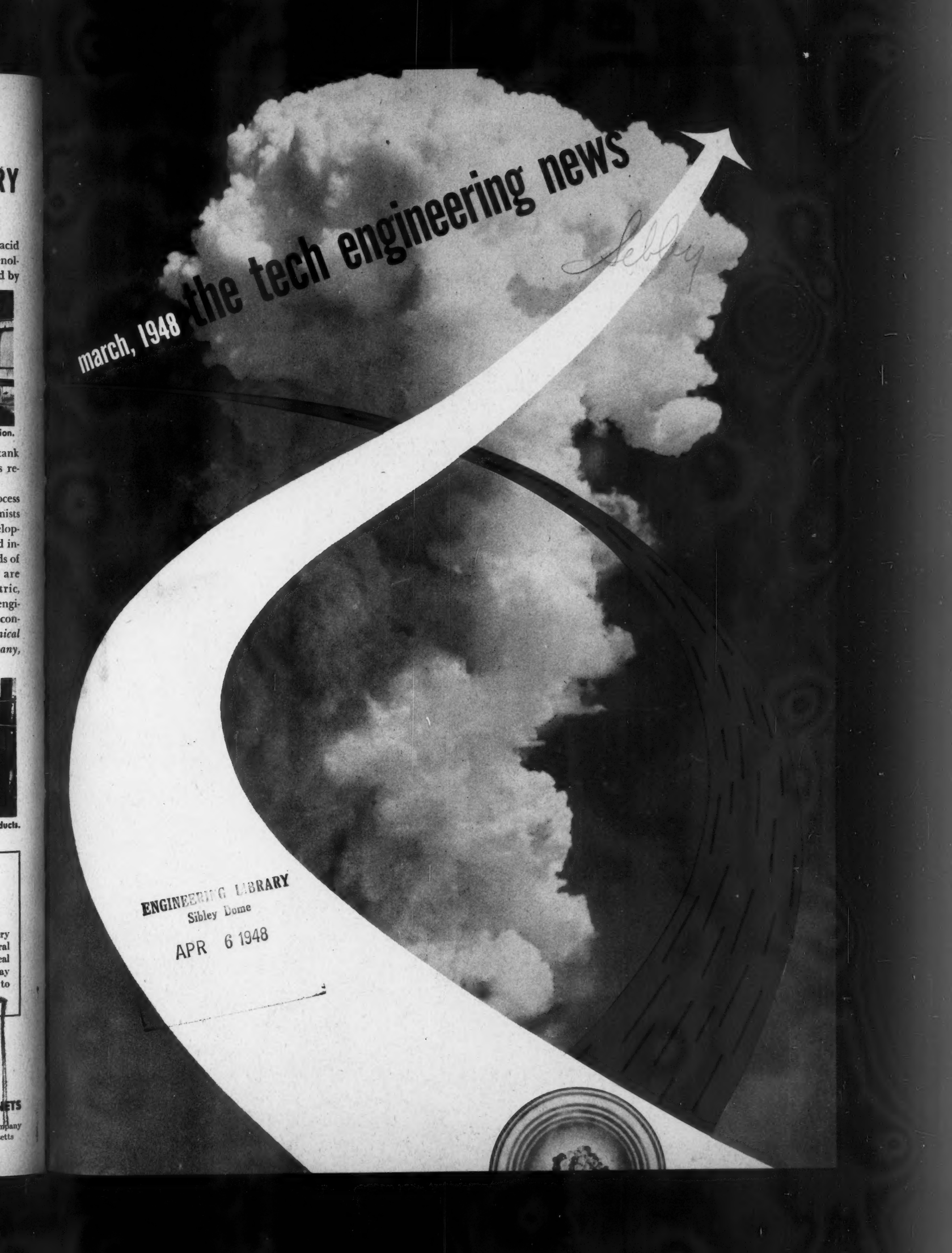

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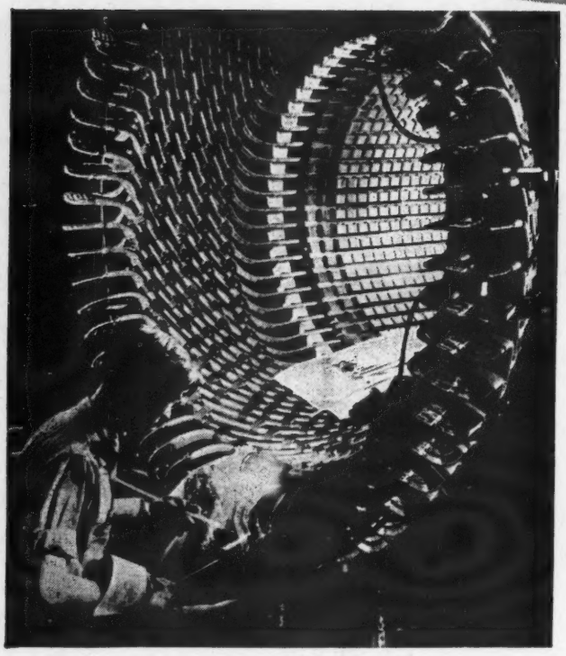

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Budd

Briefing the News . . .

Radiation Protection . . .

A POWERFUL new biological agent for defense against the effects of radiation has been developed by two staff members of the University of Rochester, Drs. P. E. Rekers and John B. Field. The essential chemical, called rutin, can be derived from a variety of sources, including the buckwheat plant. It operates by strengthening the walls of the blood vessels and preventing the hemorrhages that often follow severe irradiation.

Experiments carried on with dogs who had been fortified with doses of rutin showed the effectiveness of the new drug. Subjected to normally lethal doses of x-rays, the great majority of the protected animals survived the radiation, although they remained in a state of profound shock for nearly two weeks. Other dogs, which had not been protected by the new agent, died from the effects of the x-rays, largely from hemorrhages; blood analyses showed the absence of the normally clotting components of the blood and the presence of large amounts of the powerful natural anti-clotting agent, heparin.

Many of the people who died as a result of the Nagasaki explosion succumbed from extensive bleeding produced by the neutron and x-ray radiation. It is therefore possible, according to the Rochester scientists, that rutin may prove some defense against the terrible atom bomb.

New Standard for Measurement . . .

The National Bureau of Standards recently announced that a new ultimate standard of length may be adopted to replace the standard meter rod, which has been our standard of length for over fifty years. The new potential standard is a certain wavelength of green light radiated by an isotope of mercury, mercury-198, which is not present in nature but can be made in an atomic pile by bombarding gold with neutrons. Using techniques now available, the wavelength of the mercury spectral line can be measured to one part in a hundred million, and the bureau expects to develop apparatus that can measure the wavelength to one part in a billion.

The spectral lines of elements are often very sharp, having an exact wavelength reproducible to one part in many millions. This accuracy so far exceeds the accuracy with which the primary standard of length, the platinum-iridium meter bar of the Bureau of Standards, can be measured that for purposes of precise measurement scientists have used spectroscopically-defined standards for quite a while. The wavelength of certain red line of cadmium has served this purpose within recent years. Unfortunately, most elements exist as a mixture of several isotopic forms of different atomic weights and thus slightly different spectra. This causes the spectral lines of the element to appear blurred. The mercury produced by neutron bombardment, however, is a pure element of a single atomic weight, and hence many of its spectral lines, including the green one mentioned before, are extremely sharp.

One very great advantage of the mercury standard is that every laboratory can have a primary standard of its own. The mercury line is easily generated by passing alternating currents of high frequency through a glass tube filled with mercury-198 vapor.

Nickel Plating . . .

The United States Bureau of Standards has also revolutionized the nickel-plating industry by developing a chemical bath from which nickel can be deposited without the use of electricity.

Until about a month ago, the only known means of successfully nickel-plating an iron or steel object was to deposit the nickel on it electrolytically, by passing a current through a water solution of a nickel salt, or else to alloy the surface directly with molten metal. In order to deposit a firm and smooth coating electrically, the object to be plated usually had to be given a preliminary coating of copper. Both the deposition of copper and the electrolysis of the nickel salts were cumbersome and expensive.

In order to nickel-plate with the Bureau's new formula, however, the bath is merely heated to near the boiling point of water and the article to be plated is immersed in the solution, whereupon an adherent deposit of nickel soon forms. The process works very well with iron and steel objects, giving a more uniform deposit than the old method and requiring less time. With other metals, such as copper and lead, the new plating process does not give as firm a deposit of nickel as the older method, but since most objects commonly nickel-plated are made of iron, this is not a serious drawback to the process.

The plating bath is a water solution of nickel chloride, ammonium chloride, sodium citrate and sodium hypophosphite. The nickel salt furnishes the nickel to be deposited, and must be replenished periodically if the plating is continued for an extended length of time. The sodium hypophosphite reduces the nickel salt to the metal. Since it is a good reducing agent only at elevated temperatures, nickel deposits from the bath only when it is heated. This means that the plating solution can be stored for long periods of time at room temperature without decomposition. The ammonium chloride and sodium citrate prevent the formation of insoluble nickel compounds, such as hydroxides and phosphates, during the course of the reaction, and perhaps aid the formation of an even and tenacious layer of nickel.

For use as a plating bath, the Bureau recommends about a three per cent solution of nickel chloride, five per cent of ammonium chloride, one per cent sodium hypophosphite and ten per cent sodium citrate by weight.

Pasteurization: One Second . . .

The Radio Corporation of America has recently announced that milk can be pasteurized in a fraction of a second by exposing it to high-frequency electromagnetic fields. In the process the bacterial count drops from around 50,000 to about 100, an unusually low figure. The milk is simultaneously homogenized by the action of the rapidly fluctuating electromagnetic field on the tiny oil droplets suspended in the milk.

The process is a direct outgrowth of the induction heating processes widely used in industry today to form plastics and to heat metals to a red heat by exposing them to high frequency electromagnetic waves. A similar procedure is now used in some hotels and restaurants to cook foods through in a flash by exposing them to ultra-high-frequency radio waves.

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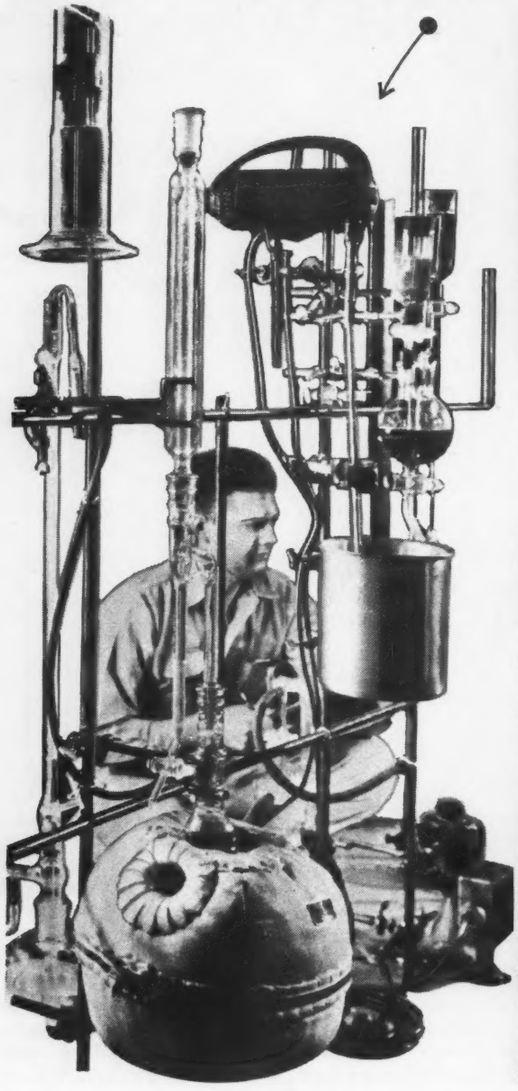

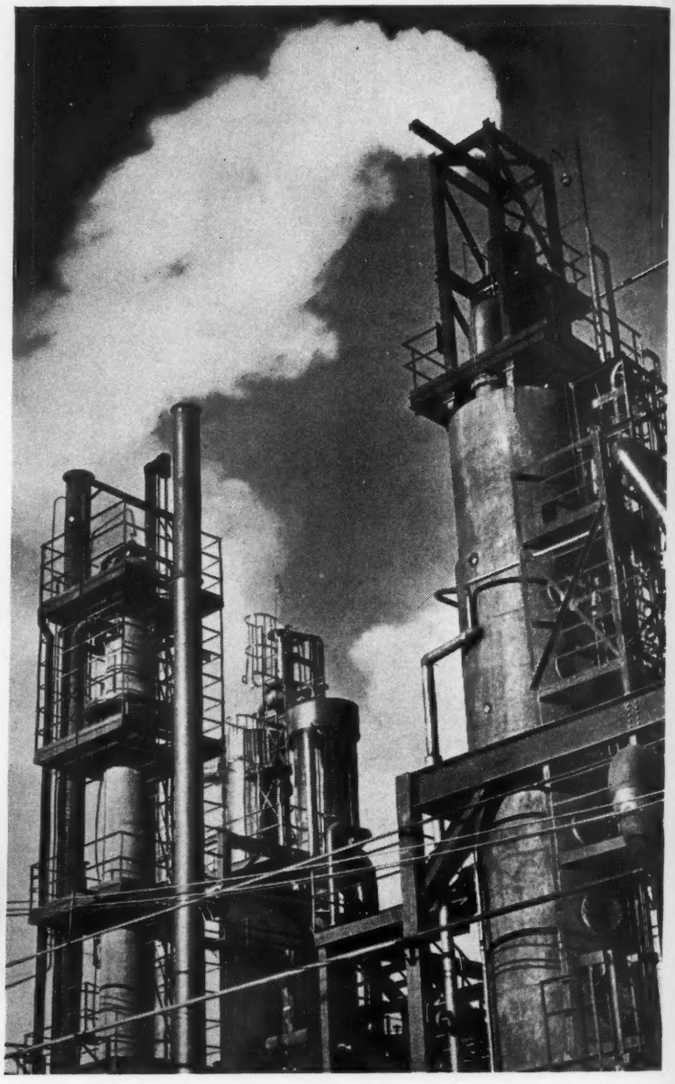

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The picture left shows a reduction of a triglyceride to an alcohol by the classic Bouveault-Blanc process, in one of the research laboratories. For years this was a laboratory curiosity. Recent research, however, increased yields and brought the possibility of commercial use.

The picture right shows the colossus that has grown out of this research. It's a new P AND G plant, now using sodium in tank car lots to produce fatty alcohols.

Between the two lies the whole story of science at P AND G—of chemists and engineers working together to create new products and new processes and to design, build, and operate new equipment and new factories.

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The TECH ENGINEERING NEWS

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This health physics inspector, covered completely by his protective clothing and mask, is measuring radiation intensity with a fishpole meter.

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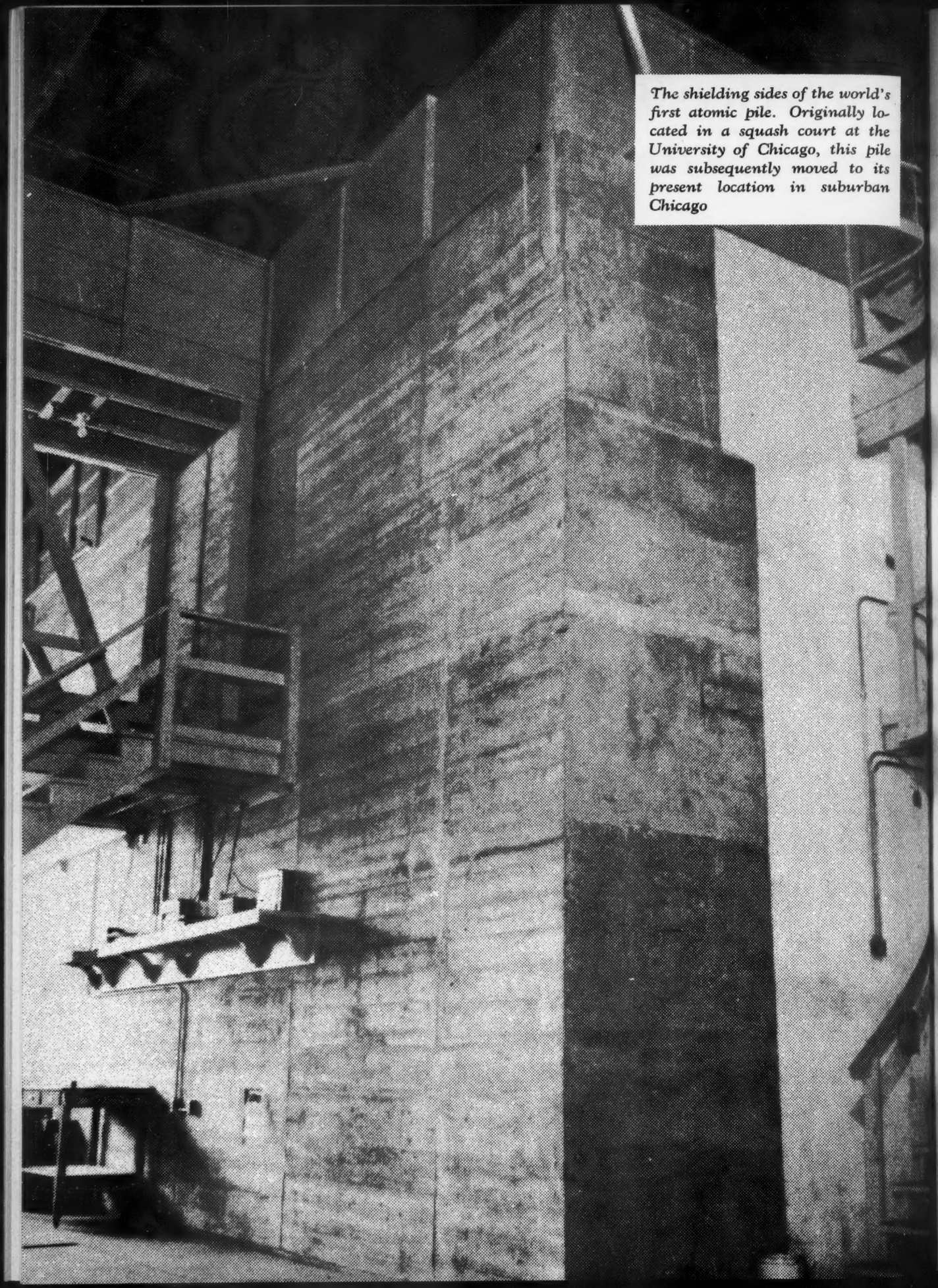

The shielding sides of the world's first atomic pile. Originally located in a squash court at the University of Chicago, this pile was subsequently moved to its present location in suburban Chicago

Nuclear Principles of Nuclear Reactors

By CLARK GOODMAN

Associate Professor of Physics, Massachusetts Institute of Technology

ALL present-day practicable schemes for utilizing nuclear energy transfer the heat produced by a neutron chain-reacting system to a working fluid and convert this heat to useful power by conventional methods. Basically, therefore, a nuclear power reactor is simply a new type of heat source, inherently capable of delivering its energy at a very high temperature level. However, because of the restrictions imposed by the physical properties of structural materials, it is limited to the moderate temperatures encountered in the use of chemical fuels.

Production of Heat

Fission Fragments

When a uranium, or other heavy atom, undergoes fission, it splits into two nearly equal fragments. These fission fragments fly apart in opposite directions with very high velocities (1,000 to 10,000 miles per second). Because of the strong electrostatic interaction between the fission fragments and any surrounding atoms, the range of these fragments is less than a thousandth of an inch in solid materials. The kinetic energy of the fission fragments accounts for about 80 per cent* of the total fission energy. The remainder is divided between the prompt radiations (about 4 per cent), emitted essentially simultaneously with fission, and the delayed radiations (about 16 per cent) emitted during the radioactive decay of the fission fragments and following absorption of stray neutrons.

The average distribution of energy production in U^{235} is approximately as follows:

	Per Cent
Fission fragments	80
Neutrons	
Prompt	2
Delayed	.004
Gamma rays	
Prompt	2
Radioactivity	3
Neutron absorption	4
Beta rays	
Radioactivity	3
Neutrinos	
Radioactivity	6

The neutrinos are not absorbed to any appreciable extent even by solid materials, hence they escape from the reactor, and presumably from the earth without producing any detectable heating effect.

* The average energy of the fragments is about 160 Mev out of a total of 200 Mev. The Mev (million electron volt) is the common unit of nuclear energy, 1 Mev = 1.6×10^{-6} erg. = 10^{6} ev.

Power Considerations

It is of some interest to consider the relationship between the power produced in a thermal reactor and the flux of neutrons, nv, where n is the number of neutrons per cm³ of velocity, v cm per sec. From the preceding section, a total of 188 Mev of heat energy is released per fission. Since the number of thermal neutrons absorbed per unit volume per unit time is nv/λ_a, where λ_a is the absorption mean-free-path of thermal neutrons in the reactor, and about 50 per cent of the thermal neutrons absorbed in the reactor give rise to fission, the power is given approximately as:

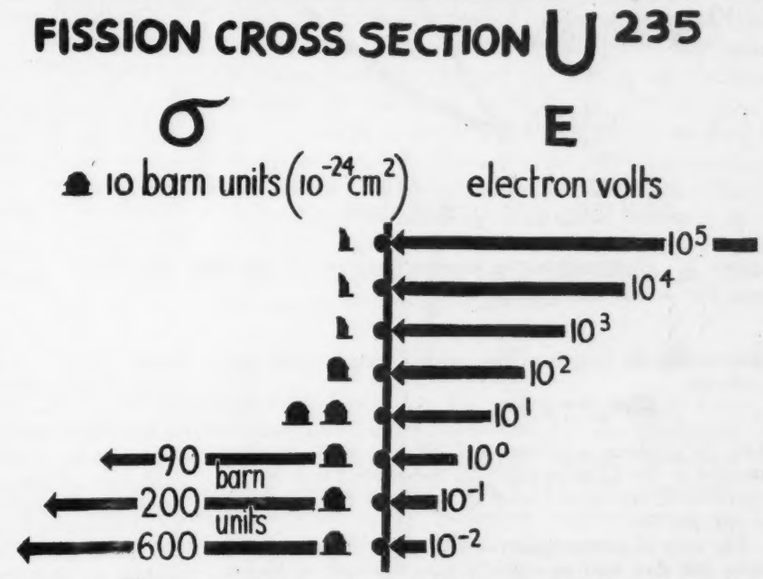

Figure 1. The approximate value of 500 barns at .025 ev is based on averages from pre-1941 literature. (See Reference 4, page 73.) The indicated cross section of 1 barn in the region from 10^3 to 10^5 ev is based on similitude with other heavy nuclei. (See Reference 4, pages 287–289.)

$$0.5\times188\times1.6\times10^{-13}\frac{nv}{\lambda_a}$$

$$=1.5\times10^{-11}\frac{nv}{\lambda_a}\ \text{watts/cm}^3 \qquad (1)$$

In a hypothetical, cubical pile of graphite and uranium, one cm on an edge, Fermi (1) cites a value of $\lambda_a = 350$ cm. He also points out that the power is not produced uniformly throughout but is a maximum at the center and decreases to essentially zero at the edge. Hence, for the example cited, the integrated power P is related to the flux n_0v at the center by the formula:

$$P\approx3.8\times10^{-12}\frac{n_0v}{\lambda_a}a^3$$

$$=1.1\times10^{-14}n_0va^3\ \text{watts} \qquad (2)$$

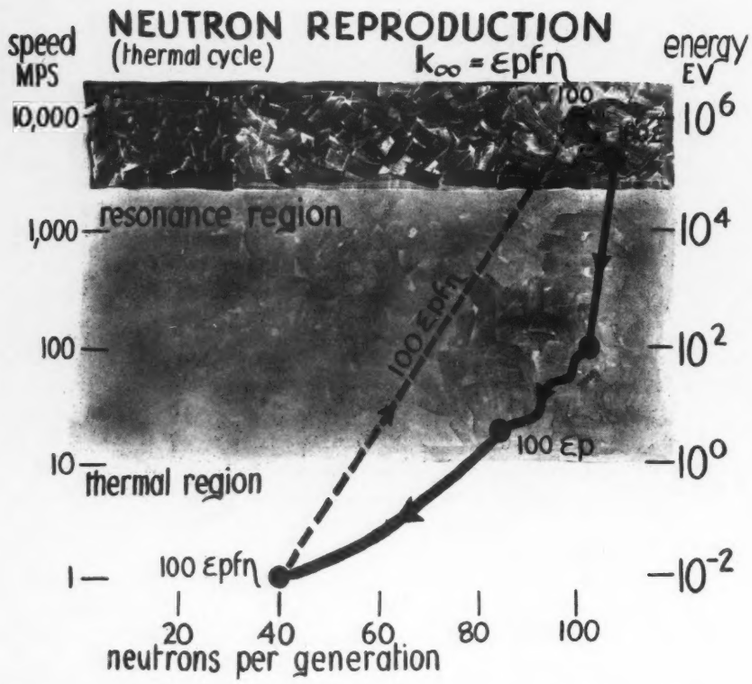

Figure 2. Diagrammatic representation of the Reproduction Cycle for a thermal reactor

Substituting the length of the critical size, $a = 584$ cm, we obtain:

$$P \simeq 2.2 \times 10^{-6} n_0 v \text{ watts.} \qquad (3)$$

Thus, to produce a power of 2,000 kw, such as that obtained in the Clinton pile (2), the central flux of the hypothetical pile would need to be about 10^{12} neutrons per cm² per sec.

The rate of consumption of U^{235} would be about 2¼ grams per day and practically this amount of fission products would be produced per day. Using the empirical relations given by Way and Wigner (3), it is seen that the radioactive power dissipation would be 23, 15, and 9 kw at 0.1, 1, and 10 days, respectively, after shutdown of the pile. This is illustrative of the important fact that a nuclear reactor continues to generate appreciable amounts of power for some time after the chain reaction is stopped.

Chain Reaction Propagation

General Considerations

In chain reactions of the type we are considering, uranium or plutonium nuclei undergo fission upon absorption of neutrons. As a result, there are liberated high velocity (fast) neutrons which may or may not be slowed down before being absorbed in part by other uranium or plutonium nuclei to produce neutrons of the second generation. In order to maintain a chain reaction, the number of neutrons in each generation must be equal to or greater than the number in any previous generation, i.e., the rate of production must be equal to or greater than the rate of loss.

The loss of neutrons is divided between absorption and leakage. The absorption is largely by uranium or plutonium nuclei and, to a minor extent, by structural materials and impurities. Leakage depends on the size and shape of the nuclear reactor and, of course, is kept to a minimum by surrounding the active volume with a neutron reflector.

Nuclear Cross Sections

The probability of a nuclear process depends on (*a*) the particular particles involved in the reaction, (*b*) the energy of the incident particle, which depends only on the speed of the particle relative to the struck nucleus, and (*c*) the angular momentum properties of the reaction. The cross section σ gives a complete specification of the probability of a reaction and is defined as the ratio of the number of interactions per nucleus per unit time to the flux of incident particles:

$$\sigma = \frac{\text{interactions per nucleus per unit time}}{nv}$$

Three types of cross sections are of particular interest in the propagation of a chain reaction:

$\sigma_f \equiv$ the fission cross section
$\sigma_a \equiv$ the absorption cross section
$\sigma_s \equiv$ the scattering cross section

The generally accepted unit of cross section is the barn (1 barn $= 10^{-24}$ cm²). The name has its origin in the colloquial expression "as big as a barn." Figure 1 is a stylized diagram of the variation of the fission cross section of U^{235} with neutron energy. It is seen that $\sigma_f(U^{235})$ increases rapidly with decrease in the kinetic energy of the neutron. At birth the fission neutrons have speeds of about 10,000 miles per second (10^6 ev). They are slowed down by collisions with nuclei — the lighter the nucleus the greater the decrement in energy of the neutron for each collision. On the average, it requires the following number of collisions to slow down a neutron from 10,000 mps to 1 mps: 18 in hydrogen, 50 in beryllium, 110 in carbon and 2100 in uranium. At this low speed the neutrons are in kinetic equilibrium with the thermal agitation of atoms. Hence, such slow neutrons are called "thermal" neutrons. They have a much greater probability of causing fission in U^{235} than faster neutrons. Advantage is taken of this increase in cross section with decreased speed in the design of nuclear reactors. Reactors which depend upon thermal neutrons to cause fission are called "thermal reactors." The chain of circumstances that maintains such reactions is known as a nuclear thermal cycle. Figure 2 illustrates a cycle of this type.

Thermal Cycle

The multiplication factor k is defined as the ratio of the number of neutrons in one generation to the number of neutrons in the immediately preceding generation. In order to separate out the effect of leakage, the problem is divided into two parts. First, the multiplication factor k_∞ is calculated for a very large (in effect infinite) medium identical in composition with the chain-reacting system being considered. The system is assumed to be sufficiently large so that the leakage of neutrons from its surface is negligible. The actual multiplication factor k is then obtained from k_∞ by

multiplying by the appropriate leakage factors. In Figure 2 we begin in the upper right with an arbitrary number of fast neutrons, for example, 100, immediately after their production by fissions in the reactor. As indicated, an average energy of about 10^6 ev is assumed, corresponding to a speed of about 10,000 mps. A small fraction $\epsilon - 1$ further neutrons are produced by fast fission.*

These 100ϵ fast neutrons begin to be slowed down by collisions with the moderator.† Thus, essentially 100ϵ neutrons enter the so-called resonance region between about 10^5 and 1 ev. Some absorptions take place in slowing down from 10^5 to about 10^2 ev. However, the predominant absorption in the resonance region occurs below the speed of about 100 mps, particularly if U^{238} is present (see Figure 3). Because of the large resonance absorption in U^{235} only a fraction p of the 100ϵ neutrons are slowed down to energies slightly above the thermal region, which lies below about 1 ev. p is known as the *resonance escape probability* and is always less than 1, whereas ϵ, the *fast effect*, is always equal to or slightly greater than 1. As the neutrons slow down still further in the thermal region, increasing fractions are absorbed in U^{235} because of the rapid rise of $\sigma_f(U^{235})$ with decrease in energy. An average fraction f of the $100\epsilon p$ neutrons is absorbed in U^{235}. The remaining number — in Figure 2 this is assumed to be 40 per cent of the original 100 neutrons — are either absorbed in the moderator, in structural materials or in U^{238}, and hence are wasted as far as the thermal cycle is concerned. Assuming that each neutron absorbed by U^{235} produces a new fission $100\epsilon pf\eta$, new fast neutrons are produced in the second generation. The dotted line indicates that the thermal cycle will just be maintained when $100\epsilon pf\eta = 100$. This corresponds to

$$k_\infty = \frac{100\epsilon pf\eta}{100} = \epsilon pf\eta = 1.000$$

In other words, a mixture of materials which would satisfy these conditions would require an infinite amount in order to maintain a chain reaction. Since we certainly want a practical reactor to be of finite size, its k_∞ must be greater than 1. The larger the k_∞ the smaller the actual size of our reactor.

A similar argument can be applied to the determination of the reproduction k of a finite reactor, if we also include a leakage factor l_f for the fast neutrons and a leakage factor l_{th} for the thermal neutrons. In this case, $k = \epsilon pf\eta l_f l_{th}$. In such a reactor, operating at a constant power level, this k must be exactly 1.0000 (see Reference 4, pp. 111–230).

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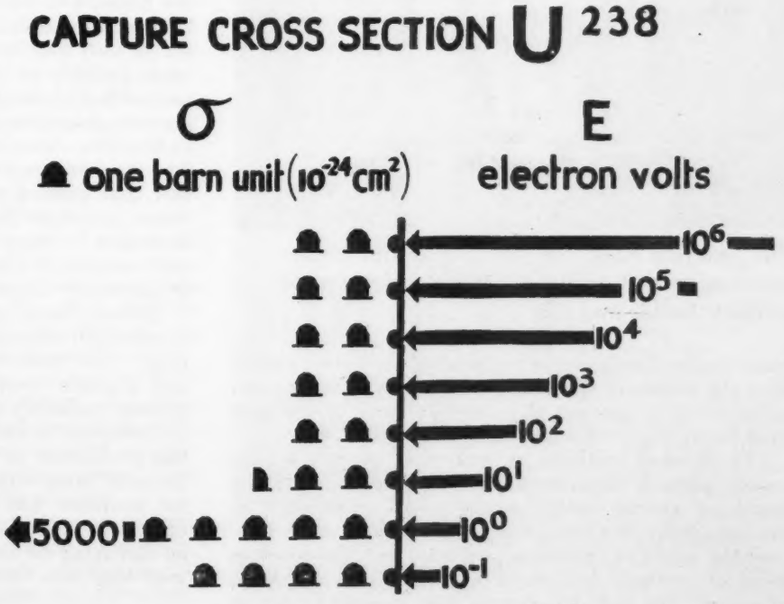
Editor's Note: Last fall when the nuclear science issue was first conceived in the minds of the T. E. N. *editorial staff, Professor Clark Goodman was immediately thought of as the man who could help and advise us on this large undertaking. He is the professor in charge of M. I. T.'s course entitled Introduction to Nuclear Engineering which both authors Jules Levin and John Weil are taking. Professor Goodman received his B.S. at the California Institute of Technology in 1932. In 1936 he came to M. I. T. as an assistant in physics, and he received his Ph.D. here in 1940. From 1942 to 1945 Professor Goodman served as a consultant for the Manhattan District. He was a technical aide in Division Seventeen of the N.D.R.C. during the years 1944 and 1945. In 1945 Professor Goodman was senior physicist in the Clinton Laboratory, Oak Ridge, Tennessee.*

Figure 3. A height of 5,000 barns for the resonance peak at 5 ev is taken from the experimental value of Anderson (5). By similitude with other heavy elements, there are probably minor resonance peaks at slightly higher energies, not shown on this diagram. These higher resonances account for the extra wiggles shown in Figure 2 just below 10^2 ev.



* Assuming the reactor contains ordinary uranium, 0.719 per cent U^{235} and 99.274 per cent U^{238}, most of these fast fissions would result from the bombardment of the U^{238}. Fermi (1) cites a value of $\epsilon \simeq 1.03$ for a well-designed heterogeneous reactor containing graphite and ordinary uranium.

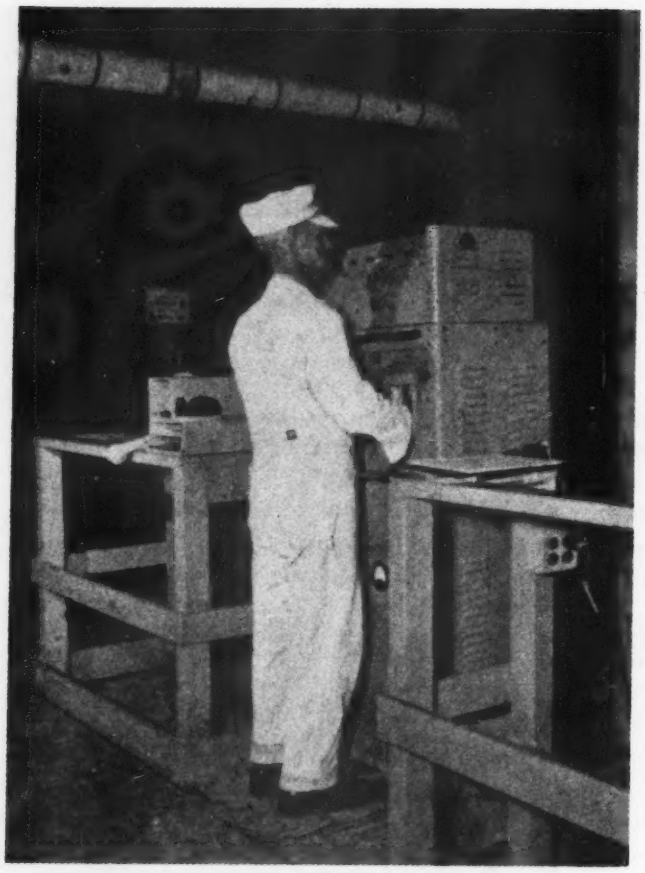
† Light elements which have low absorption cross sections for neutrons are the best materials for moderators. Outstanding among these are deuterium, beryllium, carbon, oxygen, and, to a lesser degree, ordinary hydrogen. (See Reference 4, p. 309.) In the above discussion, it is assumed that the moderator is uniformly mixed with uranium.

Health Physics

The Protection of Workers from Harmful Radiation

By RALPH C. JOHNSTON, '50

WHEN the first atomic pile was being planned at the University of Chicago in 1942, it was realized that large scale nuclear fission would create many problems concerning the safety of workers in areas where intense radiation existed. Prior to the operation of the first pile, the only sources of radioactivity had been radium and x-rays; yet, since the discovery of x-rays in 1895, hundreds of people had been killed or injured by the misuse of radium and x-rays. All this had happened when a few men handled only one or two curies of radium at the most. With the beginning of pile operations, however, it became necessary, as a routine procedure, for men to work with thousands of times as



The fourfold hand counter which uses Geiger counters to spot possible contamination on the workers' hands and feet

many curies of radioactive material as had been handled since the discovery of radium. Obviously, a means had to be found to prevent the accident story of the past from being repeated and multiplied many fold.

To discover methods of protecting personnel near atomic piles, a department for the protection of the health of atomic energy workers was established at the University of Chicago in 1942. It had as its purpose the study of radiation problems and the development of methods for protecting men from radiation exposure. The new department soon became known as the Health Physics Group, and as new laboratories and plants were built at Oak Ridge and Hanford, new Health Physics groups were formed.

While local conditions at the plants may present special problems, all three of the groups have the same basic fields of action:

1. Development of new instruments and techniques for the prevention of harmful radiation.
2. The determination of safe tolerance levels of radiation and proper shielding methods.
3. Examination of personnel to prevent overexposure.
4. Monitoring of buildings and air in the working area.
5. Surveys of air and water in off-area neighborhoods to prevent dangerous contamination.
6. Educational programs to instruct all personnel handling radioactive material in the methods of following protection measures.

To effectively shoulder these responsibilities, the Health Physics groups are generally divided into three parts: (1) Research and Development, (2) Personnel Monitoring, and (3) Surveys.

Let us consider the responsibilities of the three parts separately. First, the research and development group. One of the first problems facing the newly organized Health Physics Department was the calculation of the size and type of adequate shielding around the piles to be built at Oak Ridge and Hanford. The shielding problem was quite complex due to the fact that an operating pile creates about thirty different radioactive elements from the fission of uranium. Each of these elements gives off radiation of different types and intensities. All of these elements are beta emitters, and most of them give off gamma rays. Four radioactive transuranic elements with half-lives of from a few minutes to thousands of years have been announced that produce alpha, beta, and gamma radiation. There are at least four delayed neutron emitters with a maximum half-life of about a minute. In addition to the radioactive elements, all stable elements placed in a pile become radioactive, thus raising the total number of radioactive elements and isotopes to several hundred. The shielding problem was further aggravated by the fact that gamma rays are most effectively stopped by dense materials like lead, while a light material like hydrogen is most efficient in stopping fast neutrons, and elements like boron and cadmium are most effective in capturing slow neutrons.

Before shielding could be designed, it was necessary to establish tolerance levels for exposure to all types of rays. The American Advisory Committee on X-rays and Radium Protection set the tolerance for x and gamma radiation at 100 milliroentgens (mr.) per day. (A roentgen is defined as the radiation equivalent to the production of 1.6×10^{12} ion pairs per cubic centimeter of human flesh.) The choice of a tolerance level for neutrons was more difficult because experiments have indicated that fast neutrons are about five times as damaging to tissue as x or gamma rays. The tolerance level was thus set at 20 milliroentgens equivalent

(*Continued on page 208*)

The Preparation and Study of Radioactive Isotopes

By KENNETH KOPPLE, '51

BOMBARDING atomic nuclei with nuclear particles from the uranium reactor and the various ion accelerators, chemists and physicists have been changing atomic numbers and atomic masses to produce new elements and variations on old ones.

Immediately after their birth, such transmuted elements are in an excited state and continue to emit radiation for some time, thus falling into the "radioactive" classification. The study of the chemistry of these atoms, excluding the anomalous chemical effects produced as a result of intense radioactivity, is known as radiochemistry. Nuclear chemistry, something different from radio chemistry, studies the nuclear reactions which enter into the production of artificial elements.

Artificial nuclear transmutations are brought about by projecting light nuclear protons into close proximity with the nuclei of target atoms. The two devices in most common use today for such work are the uranium "pile" and the cyclotron, a form of charged particle accelerator.

Two particles, the neutron and the deuteron, have had the widest use in the production of radioactive isotopes. The neutron, because it has no electrostatic charge, can approach a target atom at comparatively small distances, allowing a relatively high probability of its capture by the nucleus. Once the target atom has captured the neutron, there are several steps which may follow. The neutrons produced in the uranium pile, moving at comparatively low velocities, enter into a type of nuclear reaction which involves neutron capture and subsequent emission of energy in the form of gamma radiation. Over one hundred cases of this reaction have been studied. The product nucleus may easily be radioactive, emitting a negative electron and increasing in atomic number. An example is the reaction of chlorine 37 with a slow neutron to give a beta-particle emitter, chlorine 38.

$$_{17}Cl^{37} + {}_{0}n^{1} \rightarrow {}_{17}Cl^{38} + \gamma$$

Fast neutrons, usually produced by primary reactions in a cyclotron, such as deuteron bombardment of lithium or beryllium, enter into several other important reactions:

(*a*) $${}_{z}T^{a} + {}_{0}n^{1} \rightarrow {}_{z-1}P^{a} + {}_{1}H^{1}$$

(*b*) $${}_{z}T^{a} + {}_{0}n^{1} \rightarrow {}_{z-2}P^{a-3} + {}_{2}He^{4}$$

(*c*) $${}_{z}T^{a} + {}_{0}n^{1} \rightarrow {}_{z}P^{a-1} + 2\,{}_{0}n^{1}$$

In reaction (*a*) a neutron is captured and a proton ejected. The resultant nucleus usually emits an electron during radioactive decay to its original form. In (*b*) an alpha particle is emitted after neutron capture, but the yield is low and the reaction occurs best with elements of atomic number less than thirty. Reaction (*c*) involves the emission of two or more neutrons after the original capture. This reaction is known to produce radioactive isotopes in over eighty cases. The resulting nucleus is usually a positron emitter.

The deuteron, a combination of neutron and proton, is the nucleus of the heavy hydrogen atom. It carries a single positive charge and therefore approaches a target nucleus less easily than the neutron. However, it is favored over other charged particles such as the alpha particle (the helium nucleus).

Some of the important deuteron reactions can be classified, although once a deuteron has been captured totally by a nucleus, the energy level is so high that a number of disintegrations can take place.

(*a*) $${}_{z}T^{a} + {}_{1}H^{2} \rightarrow {}_{1}H^{1} + {}_{z}P^{a+1}$$

(*b*) $${}_{z}T^{a} + {}_{1}H^{2} \rightarrow {}_{0}n^{1} + {}_{z+1}P^{a+1}$$

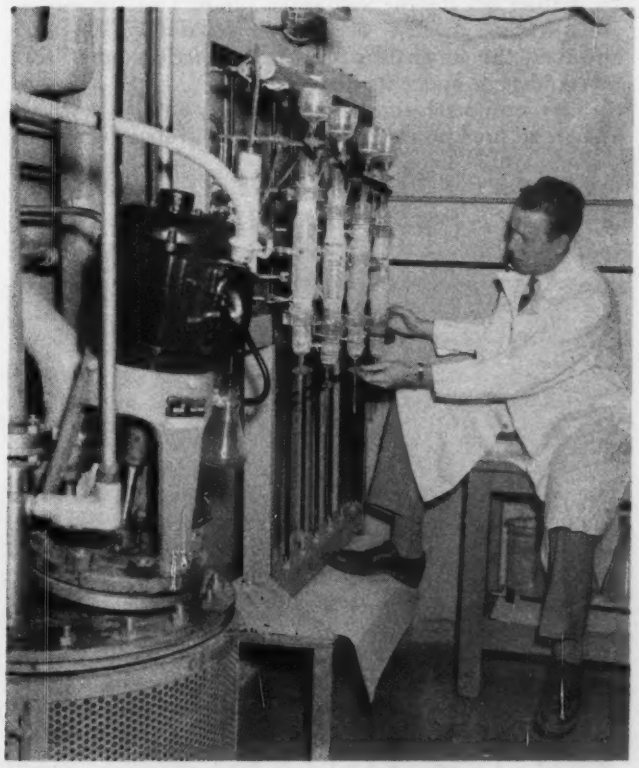
(*c*) $${}_{z}T^{a} + {}_{1}H^{2} \rightarrow 2\,{}_{0}n^{1} + {}_{z+1}P^{a}$$

(*d*) $${}_{z}T^{a} + {}_{1}H^{2} \rightarrow {}_{2}He^{4} + {}_{z-1}P^{a-2}$$

There are other possible reactions, but they have lower yields and are useful in only a few cases. Reaction (*b*) is the most efficient of the reactions in which the whole deuteron is captured, and is known in about seventy cases. The products of this reaction emit either positive or negative electrons. Reaction (*c*) results in the replacement of a proton with a neutron and produces a positive electron emitter. Reaction (*d*) results in reduction of both atomic number and atomic mass and is known in numerous cases.

As can be seen, bombardment of atoms with nuclear particles can lead to changes in both atomic number (z) and weight (a). Where the atomic number is changed, purely chemical methods can be used to separate the product from the target in which it was produced. Where only atomic weight is changed by the

Apparatus for separating radioactive carbon from calcium nitrate after it has been bombarded in a chain-reacting pile Clinton National Laboratory



irradiation, and the product therefore has the same chemical properties as its target-parent, separation can rarely be performed.

There is one special case where radioactive isotopes of an element can be separated from a target of the same element. When an alkyl halide, such as ethyl iodide, is irradiated with slow neutrons, most of the induced radioactivity can be extracted with water. This radioactivity is due to iodine 128, a radioactive isotope of iodine, formed by neutron capture and gamma-ray emission from iodine 127. The explanation of this phenomenon lies in the fact that, while emitting the gamma particle after neutron capture, the target nucleus acquires a recoil energy sufficient to rupture the chemical bond which holds it, becoming a free iodide ion, soluble in water. This Szilard-Chalmers process, known for its discoverers, is applicable to a number of cases, although it has one important requirement. If any chemical exchange exists between the bonded target atom and the product atom, the separation produced by the recoil energy is nullified. With the ethyl iodide and iodine ion, there is only slow chemical exchange and separation is possible. However, if an ionic iodine compound were used, sodium iodide, for example, a greater exchange would exist and separation would be small.

One use of the Szilard-Chalmers process is in the production of radioactive arsenic 76 from the common isotope of mass 75. Cacodylic acid (CH_3 As O OH), an organic arsenical, is irradiated with neutrons in aqueous solution. Those arsenic atoms which capture neutrons emit gamma rays and recoil from the cacodylic acid molecule, entering the aqueous solution. After irradiation, the solution is mixed with a minimum of arsenic chloride and the isotope precipitated in the trivalent state by hydrogen sulfide.

When substances are dissolved in solution in very small quantities, as happens when separations of product and target elements are handled, precipitation of the product with reagents used for regular analysis is usually ineffectual, since ions of the irradiation product are not present in sufficient concentration to exceed the values set by the solubility product of the desired precipitate. By use of another insoluble substance, however, the sought-for ion can be carried out of solution and thus concentrated.

Any random insoluble compound cannot be used as a "carrier precipitate." The crystalline structure of the carrier must be the same as that of the precipitate ion. For example, barium, in the same group and having the same crystalline structure in compounds as radium, is often used to carry down and concentrate radium in solution. A solution of radium sulfate, although too dilute to precipitate alone, can be cleared of radium by addition of enough barium ion to form a precipitate. The resulting substance is a "mixed-crystal" of radium and barium sulfates. This type of "co-precipitation," known as isomorphic substitution, is independent of the conditions of the precipitation.

Another type of co-precipitation, dependent upon local conditions, amounts to superficial adsorption on the surface of the carrier crystals. If the carrier has surface active portions bearing an opposite charge to that of the ion to be concentrated, this type of adsorption will often occur although the two ions are not isomorphic.

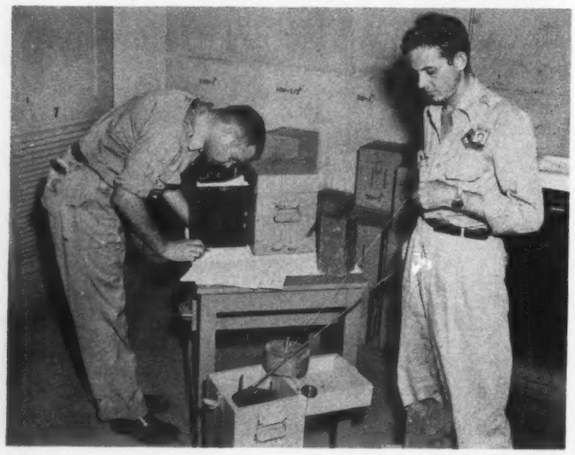
In some special cases, a combination of adsorption and isomorphic substitution will take place with the formation of "anomalous mixed crystals." The resulting precipitate contains the trace ion in what appear to be mixed crystals although no isomorphism exists.

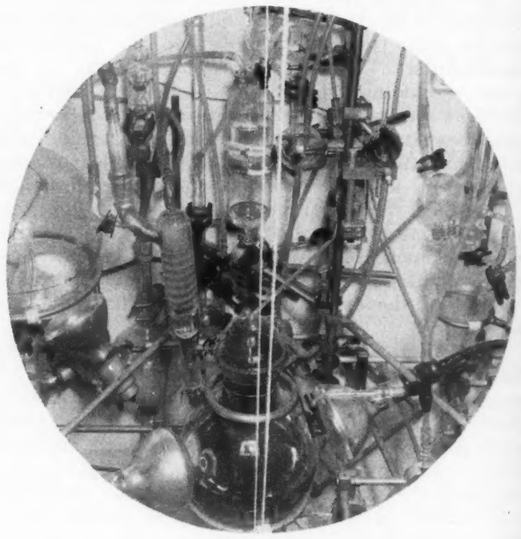
Co-precipitation with an element of different atomic number from the irradiation product is required when another isotope of the product is not available in macroscopic quantities, as with the newly discovered elements 43, 61, 85, 87, and the transuranics. However, when another isotope is freely available as often happens with most of the radioactive isotopes artificially produced, a carrier of that element may be added. Both the carrier and the isotope will follow the same separation scheme and act according to the solubility laws which hold for larger concentrations. The same conditions hold true for trace impurities which must be either kept from precipitating with the required isotope or precipitated before. Carriers used to prevent precipitation are known as "hold-back" carriers.

Often several methods of separation are combined in the separation of one product substance from its target in order to obtain the greatest efficiency.

Workers at the Clinton National Laboratory preparing a sample of radioactive iodine for shipment

Clinton National Laboratory





Clinton National Laboratory

Viewing the inside of a processing cell through a periscope. Operations are performed from the outside

GROUP IV A	GROUP V A	GROUP VI A	GROUP VII A	GROUP VIII A		
Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78
Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96

Here the transuranic elements are arranged in the periodic table according to atomic numbers only. However, chemical properties indicate the start of a new rare earth type group

An example of separation using carriers can be given by the process used to isolate iron of mass 55 which is produced by bombarding manganese with deuterons. The manganese target surface is dissolved in six-normal hydrochloric acid which is then diluted to normal. Hydrogen sulfide is then added to remove copper impurities as the sulfide. Then, carrier quantities (1–10 milligrams) of iron, cobalt, zinc, and phosphate ions are added. The iron is then removed in the form of an organic complex with cupferron, an analytical reagent for copper and iron, while the cobalt and zinc act as holdback carriers. Repetition of this process will give a good separation.

In some cases a carrier is not needed to effect a separation. Other methods, based on differential distribution between two immiscible solvents, use of scavenger precipitates such as ferric hydroxide or manganese dioxide, or electrochemical processes, will serve without the reduction in concentration occurring with carriers.

Radioactive gallium (gallium 68) which is produced from zinc by neutron bombardment, can be separated from its target-parent by reaction with hydrochloric acid and extraction of gallium trichloride by ethyl ether.

When radioactive copper is to be separated from radioactive zinc, a piece of lead foil in a solution of the two ions will cause the copper to precipitate out while the zinc remains in solution. This separation can be applied where a large difference exists between the oxidation potentials of the radioactive components.

Since substances present in solution in ultra-small quantities are all but undetectable by chemical means, it is necessary to resort to the same methods used for separation in the analysis of the chemistry of the radioactive isotopes. By tracing the radiation of the isotope during analysis, it is possible to get quantitative measurement for concentrations as low as 10^{-8} to 10^{-20} molar. In the cases of isotopes with atomic numbers equal to those of the well-known elements, a study of the chemistry is unnecessary, but artificial elements, such as the transuranic series — neptunium, number 93; plutonium, number 94; americium, number 95; and curium, number 96 — whose chemistry was not known, make it imperative to devise methods of studying the reactions of radioactive traces.

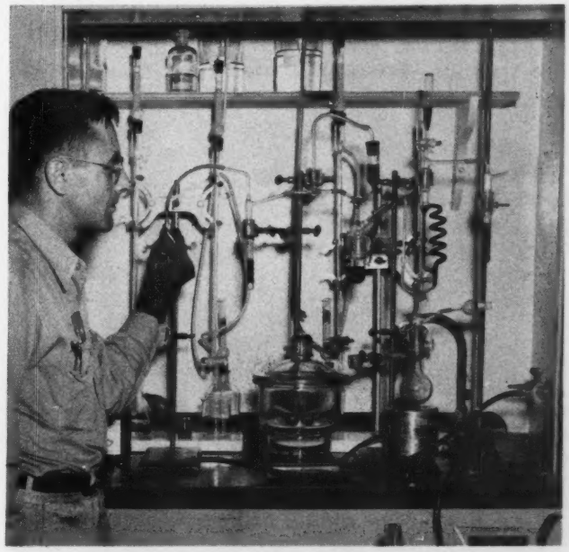
It is possible to place artificial elements in their approximate place in the periodic table when their atomic numbers are known, but without actual analytical evidence, it is not possible to postulate the actual complete chemical properties. To this end, specific carrier precipitation is used. A carrier precipitate will carry with it elements in trace quantities most efficiently when the trace is in the same oxidation state and periodic group, since the ions will probably be isomorphic. For example, cerium trifluoride will carry down elements in the II, III, or IV oxidation states if they are similar to the rare earths; and has been used as a carrier precipitating agent for traces of such elements as actinium, number 89. If the radioactive isotope in solution falls into this category, the radiation activity of the solution will be markedly reduced when the CeF_3 carrier is precipitated. Other carriers have been studied with elements whose chemistry is known, so that it is known, for example, that sodium uranyl acetate will carry down elements similar to uranium when they are in the VI oxidation state. This type of known carrier has been used to study the oxidation states of the transuranic elements.

A solution of neptunium 237, which is produced by decay of uranium 237, a pile product, will precipitate its activity with cerium fluoride when it is in acid solution treated with a reducing agent such as sulfur dioxide; but will not do so with sodium uranyl acetate. A strong oxidizing agent such as bromic acid, however, will reverse the order of precipitation. Since the type of ion which will be carried by these two reagents is known, it can be deduced that neptunium has at least two oxidation states — the upper one VI, and the lower II, III, or IV. The activity in the sulfur dioxide solution is precipitated with thorium iodate which is a characteristic of IV ions. If a reducing agent stronger

(*Continued on page 228*)

Equipment for synthesizing compounds of radioactive carbon

Clinton National Laboratory



Today's Nuclear Reactors

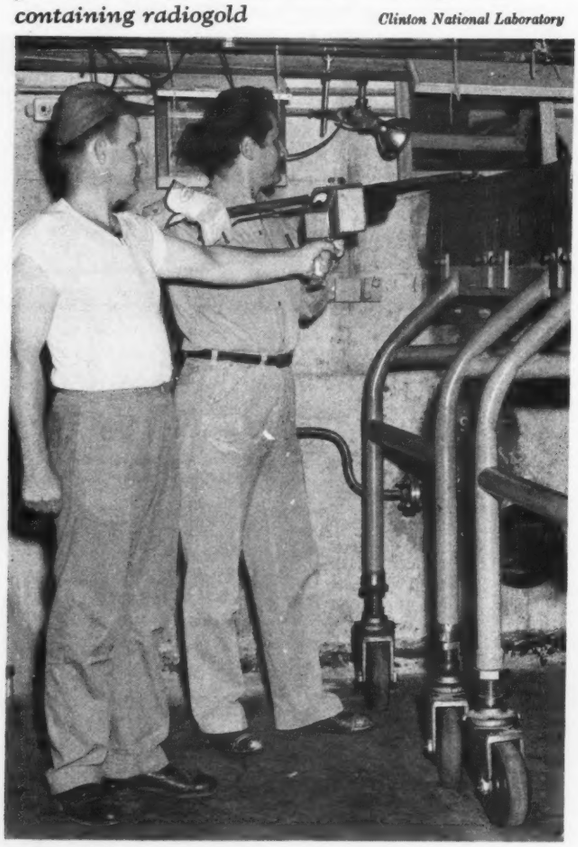
By JULES S. LEVIN, '48

THE climax of all research and development in nuclear engineering is the construction and operation of a nuclear reactor. This reactor may take the form of a so-called "pile," useful as a research tool, as a means of producing radioactive isotopes and transuranic elements, or as a new source of energy. If this energy is released in large amounts in a very short time, the reactor becomes a bomb.

To date, five atomic bombs and twelve piles which have reached critical size are described in the open literature. In addition it is known that at least six more piles are either under construction or in the late design stages. The details of construction of these reactors are closely guarded secrets; however, there is sufficient declassified information to be of interest.

3:28 p.m. December 2, 1942, marked the beginning of the first self-maintaining chain reaction initiated by man, the "Chicago Pile." Built in a squash court beneath the West Stands of Stagg Field, University of Chicago, this pile was a heterogenous thermal reactor employing graphite as the moderator and uranium and uranium oxide as the fissionable material. It was built in the form of an oblate spheroid, with a cubic lattice of lumps of the fuel embedded in bricks of graphite. Control of the reaction was accomplished by varying the positions of rods of some neutron absorber such as boron-steel or cadmium.

With the concrete wall shielding them from the pile behind it, these men are removing a can containing radiogold *Clinton National Laboratory*



The uranium metal was arranged in a lattice in the central portions of the pile and the oxide was used elsewhere. The only apparent reason for the use of uranium oxide as well as the metal was the lack of a sufficient quantity of metal to complete the project. The three lattice structures used had multiplication factors for infinite size (k_∞) of 1.07 for the pure metal lattice and 1.04 and 1.03 for the oxide. The difference in the latter two values was due to a difference in the grade of graphite used. The effective multiplication factor of the pile which was actually constructed was observed to be 1.0006. These are the only declassified values available of multiplication factors actually attainable in a nuclear reactor.

Originally it had been intended that this reactor be spherical in shape, since the volume of a just critical sphere is less than that of any other configuration, and only a limited amount of materials were available. However, the reaction became self-sustaining when construction was only about three-quarters completed and the design was therefore changed to a doorknob-shaped structure.

The Chicago pile required 12,400 pounds of uranium metal and an undisclosed amount of uranium oxide. It operated at a maximum power level of 200 watts with no provision for cooling. It was felt that operation at greater powers would be unsafe due to the high radiation intensity in the vicinity of the reactor.

After a few months of operation, the Chicago pile was torn down and reconstructed at the Argonne Laboratory, outside of Chicago, where it has been used for research purposes. The materials and lattice structure of the new pile are almost identical to those used in the original; however, this time the construction took the form of a cube rather than a sphere. This requires more materials but is a much more easily engineered structure.

The Argonne pile is surrounded by a shield, but since no cooling devices were incorporated in it, the level of operation is limited by the permissible temperature rise. The reactor can be operated indefinitely at a power level of two kilowatts, and at levels up to 100 kw. for periods of about an hour. When operated at 100 kw. the thermal neutron flux at the center of the structure is about 4×10^{10} neutrons per square centimeter per second,* the power output of a pile being proportional to the maximum flux.

Some idea of the order of magnitude of the dimensions of a typical pile may be obtained from an article by Enrico Fermi.* In this, Dr. Fermi calculates the critical size of a hypothetical reactor consisting of a lattice of uranium lumps embedded in graphite, the k_∞ of the system being assumed to be 1.06. He finds

* Enrico Fermi, "Elementary Theory of the Chain-reacting Pile," *Science*, *105*, p. 27, January 10, 1947.

the edge of a critical cube to be 584 cm., or 19.15 feet. Thus this reactor would occupy about 7,000 cubic feet. When this hypothetical pile is operating at a power level of one kilowatt, the maximum thermal neutron flux is about 4×10^8 neutrons per square centimeter per second.

With the discovery of element 94, plutonium, and the possibility of its use in an atomic bomb, it was decided to construct several large reactors for the purpose of producing useable quantities of this new element. To this end a pile was built at Oak Ridge, Tennessee, to serve as a pilot plant for the project.

The Oak Ridge pile consisted of a lattice of horizontal aluminum clad rods of uranium, distributed in a cube of graphite which served as the moderator. Rods of fissionable material were used instead of lumps since they are more easily handled and cooled. These rods are slid into channels in the graphite, space being left for air to be forced through in order to cool them, and for the rods to be pushed out the back of the pile when they are ready for processing.

This reactor is much larger than the Chicago pile. Important additions were its air-cooling system and heavier shields. Several months after the beginning of operation, modification of the lattice arrangement and other improvements allowed operation at a level greater than 2,000 kw. Today the Oak Ridge pile is engaged in producing the United States' supply of radioactive isotopes for research and medical purposes.

The main plutonium producing piles at the Hanford Engineering Works in central Washington were designed to employ water rather than a gaseous cooling fluid. Two important reasons for this change were the hazard of leakage of a gas carrying radioactive impurities, and the greater efficiency of a liquid coolant. However, in other details these piles are similar to the installation at Oak Ridge. Five reactors were originally planned, but only three were built, construction being completed by the summer of 1945. In addition, a low-powered unit was built for testing purposes. The plutonium producing reactors operate at power levels greater than 1,000 kw.

Up to this point, all the nuclear reactors discussed have employed graphite as the moderator. However, heavy water is much more effective in slowing down neutrons and also has less neutron absorption. Its excellent moderating properties permit a considerably higher multiplication factor than any other material, and therefore a much smaller critical size. But heavy water is not nearly as available as graphite.

By the fall of 1943 enough heavy water had been separated to allow the construction of a small experimental reactor. This was built at Argonne and completed in May 1944. It took the form of slugs of uranium in a tank containing the moderator. The pile operated at a power of 300 kw.

A similar pile using heavy water as the moderator was constructed by the Canadian National Research Council at Chalk River. This reactor also consists of rods of uranium in a tank of D_2O. The Chalk River pile operates at a power level of only 3.5 watts; however, just recently a high power heavy water moderated reactor which will provide an important tool for research and plutonium production has been constructed at this same site.

It has been mentioned that the use of heavy water as the moderating material reduces the critical size of a reactor. Even with its shield, the Argonne pile is relatively small compared to uranium-graphite reactors. However, to see just how small a reactor can be made, we must turn to the Los Alamos "Water Boiler."

The water boiler employs ordinary light water as its moderator. Light water is actually better than heavy water in its slowing down properties; however, it has a higher neutron absorption cross section. To overcome this disadvantage and to further reduce the size of the reactor, uranium, enriched in the thermally fissionable isotope U^{235}, was used as the fuel.

The active portion of the water boiler consisted of a stainless steel sphere only about one foot in diameter. This sphere contained approximately one kilogram of U^{235} in the form of some enriched salt of uranium dissolved in ordinary water. The sphere was surrounded by a reflector of beryllium oxide which decreased the number of escaping neutrons and therefore reduced the critical size. This reactor operated at a power level of 10 kw.

All the graphite and water moderated piles discussed so far are classified as thermal reactors. The distinction between a thermal and a fast reactor is important. These designations arise from the predominant energy at which fission takes place, not necessarily from any time element involved. In a thermal reactor the major number of fissions are produced by neutrons of thermal energies, about .025 electron volts. Since neutrons are "born" with energies of about one million electron volts or greater it is necessary to have some material present which will remove energy from these fast neutrons and bring them into "thermal equilibrium" with their surroundings. This is the purpose served by the moderator.

On the other hand a fast reactor is dependent on fissions produced by high energy or "fast" neutrons. Any moderator present would be detrimental in that it would decrease the number of neutrons capable of producing a fast fission. Since neutrons produced by fission need no moderating in a fast reactor, but can cause additional fissions at once, the ability to reach very high power levels in extremely short times is an inherent

United States Army Signal Corps

A can of radioactive material has just been removed from the pile at Oak Ridge and is being placed in a lead shipping container

feature of this type of reactor. A thermal reactor is always limited in its rate of power increase by the small but finite time required for neutrons to slow down to thermal energies. It is therefore evident that an atomic bomb is nothing more than a homogeneous fast reactor.

In order that a self-sustaining fast reaction be possible, it is necessary that the fuel have an appreciable cross section for fission at high energies. Only two elements are known which meet this requirement, U^{235} and Pu^{239}. These then were the materials used in the five atomic bombs which are known to have been exploded to date.

The first of these bombs was detonated at Alamogordo, New Mexico, on July 16, 1945, as an experiment to determine the success of the entire project. The second was set off over Hiroshima the following August 6. The third bomb, used at Nagasaki three days later, was said to be an improved type, either more powerful or more effective. The two bombs exploded at Bikini on July 1 and 25, 1946, were also of the Nagasaki type. All that is known concerning these reactors is that they released energy greater than that set free by the detonation of one hundred thousand tons of TNT.

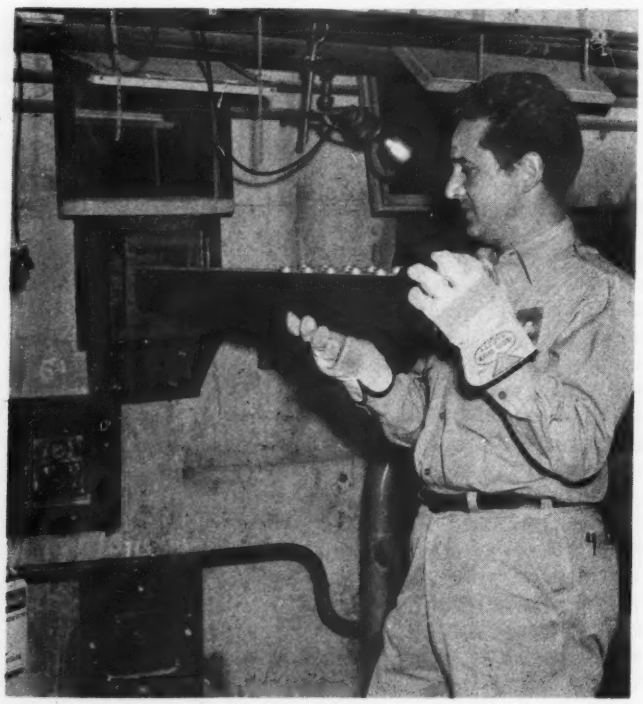
A controlled homogeneous fast reactor has been in operation at Los Alamos since November 1946. This pile employs no moderator and uses plutonium as the fissionable material. In contrast with a thermal reactor, it requires only a few pounds of material and has a very high neutron flux. The reactor has been operated at a level of only a few hundred watts, but it is quite probable that this will be increased as cooling facilities are improved. Since this reactor is in many ways similar to the bomb, it has been said that it was constructed primarily for the study of bomb physics.

Several methods by which a fast reactor might be controlled have been hypothesized.* Ordinary control rods of materials having high absorption for fast neutrons might be used; however, no elements are known which are as effective at high energies as cadmium and boron are at thermal energies. As an alternative, portions of the actual fuel could be moved with respect to each other, thereby varying the amount of fissionable material active in the reactor. If a reflector were used in order to decrease the size of the active portion of the reactor, parts of the reflector might be removed, thus increasing the leakage of neutrons out of the pile and reducing the effective multiplication factor.

*Goodman, "The Science and Engineering of Nuclear Power," Chapter 9, Addison-Wesley Press, Inc., 1947.

Chemical samples are being placed into a pile for irradiation. Because these samples are not yet radioactive, they need not be shielded

Clinton National Laboratory



Other than the United States and Canada, Britain is the only country known to have a nuclear reactor in operation. Located at Harwell, Berkshire, this pile is similar to the graphite moderated reactor at Argonne. Several hundred tons of graphite and upward of seven tons of uranium metal and uranium oxide went into its construction. The installation reached critical size in August 1947.

The reactor has only a simple cooling system and operation will probably be limited to a level of about 50 kw. At this power the maximum thermal neutron flux will be about 10^{10} neutrons per square centimeter per second, and a total of about 3×10^{15} neutrons per second will be produced in the pile. A biological shield of about five feet of concrete serves as protection against this radiation.

During the race for the atomic bomb, German scientists were not ignorant of the possibilities of a self-sustaining neutron reaction. Construction was started at Haigerloch, Germany, on a heterogeneous thermal reactor; however, it is not known whether this system ever became critical.

Today almost all the important nations in the world are making plans for the construction of nuclear reactors for research, plutonium production, and even power purposes. In England, a second reactor being built at Harwell is scheduled for completion this year. Designed for the purpose of studying problems of power production, the pile will be an air-cooled heterogeneous thermal reactor similar to that at Oak Ridge. It is expected to operate at a power level of several thousand kilowatts. The temperature of the emerging cooling gases will probably be limited to about 300° C. by the thermal properties of the aluminum cladding on the uranium rods. Although this temperature is not high enough for efficient power production, some use will be made of the pile heat.

Construction of still another pile for the purpose of producing fissionable material is scheduled to start soon at Sellafield, Westcumberland, England. In the meanwhile, just outside of Paris, French scientists are working on a reactor which is expected to reach full size in two years.

Although no information is available, it may be presumed that the U.S.S.R. has some nuclear reactors under construction and possibly already in operation.

As for the United States, construction in the immediate future seems to be concentrated at the Brookhaven and Argonne National Laboratories. Two reactors are to be built at Brookhaven, on Long Island, and construction has already begun on the first. At Argonne plans are being made for a high flux reactor several times more powerful than the pile at Oak Ridge.

Most of the nuclear reactors constructed to date or planned for the near future have been built either as research tools or for the production of additional fissionable material. It is hoped that soon more attention will be turned to solving the engineering problems involved in the practical utilization of the tremendous energy available from this new source.

The Heisenberg Uncertainty Principle

By ROBERT H. KRAICHNAN, '47

IN the last fifty years, fundamental physics has experienced rapid and accelerated progress. In the eyes of the lay public this development is symbolized by the atomic bomb and the promise of atomic power. From the intellectual point of view the development of modern atomic physics has involved new concepts and techniques which are today grouped under the general heading of "quantum physics."

Fortunately, the very technicality of the mathematical language used in formulating the new concepts has discouraged discussion of quantum physics by most lay authors. Nevertheless, there has been a great deal of talk about quantum mechanics on the part of philosophers and thinkers of varied qualifications and consequently a great deal of confusion exists. In this article we would like to touch upon, in a general way, the nature of the changes in scientific thought brought about by the new physics and to discuss the particular aspect of the new physics known as the Heisenberg Uncertainty Principle.

In order to appreciate the nature and scope of the innovations involved in the twentieth century physics it is necessary to know something of the Newtonian philosophy which directed the development of the classical physics of the eighteenth and nineteenth centuries. The basic objective of science is the accumulation of data and the construction of a pattern in which to fit the data. The particular pattern which is used should be evaluated in terms of simplicity and convenience, the ultimate practical test of a particular pattern being its usefulness in the prediction of data as yet unknown.

The earliest attempt at science was the pantheism of the primitive savage. The savage was scared and bewildered by the world about him and he sought to remove part of its arbitrariness and terror by fitting it into a pattern. The pattern he chose was based quite naturally on his own immediate experience: he assumed that nature acted the way it did because various minds and souls willed that it do so. A science based on such a pattern might have been successful except for the unfortunate fact that man's own caprices and volitions are, nowadays particularly, quite unpredictable even to himself. The construction of a useful and workable model of nature patterned after man is then even more impossible a task.

In the course of time, however, it was found that certain simple phenomena in nature could serve as models to give insight into more complicated processes. In particular, Newtonian physics, which is highly successful in explaining and predicting a wide range of physical phenomena, is based on the mechanics of massive particles. These particles are assumed to move according to definite laws under the influence of "forces" exerted between the particles. Starting from particle mechanics it was found possible to construct a very useful scientific system which gave a reasonably full explanation of the mechanics of macroscopic bodies. The mechanics of continuous media was treated as a limiting case of the mechanics of discrete particles. Thus, the theory of elasticity and sound was constructed, and, by further analogy, the classical electromagnetic theory.

The assumption that the physical world was made up of mass-points exerting certain definite forces on each other proved so highly successful, on the whole, that in the early twentieth century, the elementary particles were as real to most scientific thinkers as the macroscopic objects they handled in everyday life.

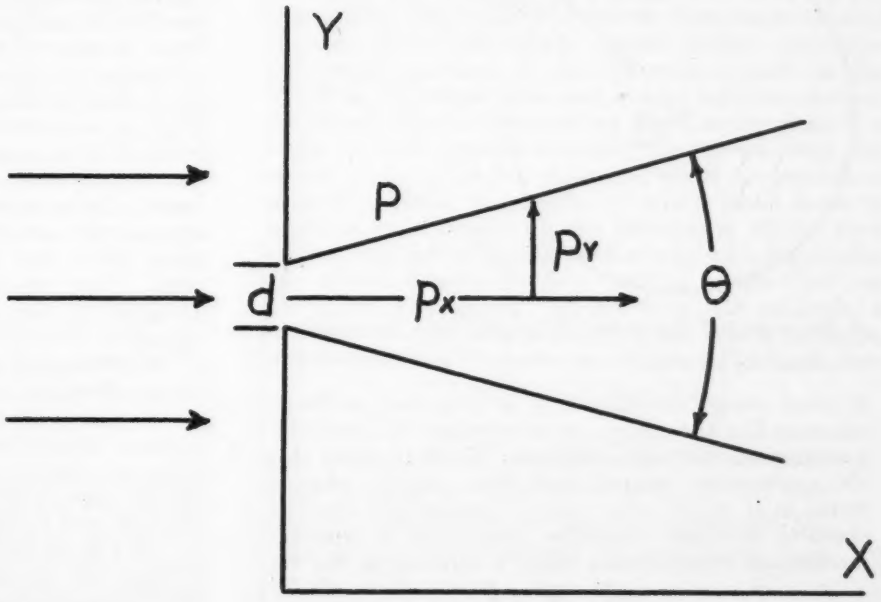


Figure 1

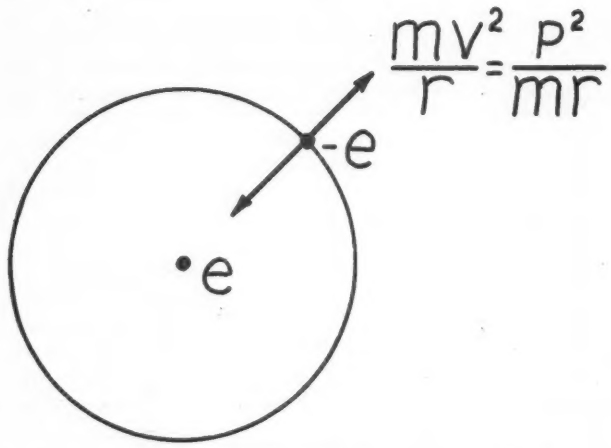
Herein there lay a grave fallacy. People confused the reality of familiar large-scale objects with the hypothetical microscopic particles which were invoked to explain macroscopic phenomena.

The biggest contribution to scientific thought made by quantum physics was to point out clearly that the reality of perceived nature is quite separate from the reality of the constructs used by the physicist in describing and predicting nature. The latter have only a formal reality in that they legitimately exist only so long as they are useful. Most of the paradoxes of quantum theory disappear if we accept the simple fact that matter is not made of the mass-points conceived by the Newtonian physicist. In other words, it has turned out that in order to give a description of nature correct to the atomic level, it is necessary to assign to the hypothetical elementary particles properties which

have no counterpart in the macroscopic mechanics with which we are familiar.

Although the quantum physicist does not deal with systems in which Newtonian mechanics is strictly applicable in the same sense that it is for ordinary systems, he nevertheless finds it convenient and helpful to speak in Newtonian terms. In fact, a large range of quantum-mechanical problems may be investigated in an approximate way by what is known as semiclassical treatment. The problem is set up in the classical manner according to ordinary Newtonian mechanics and then the quantum nature of the problem is introduced through certain conditions and limitations.

An important and useful tool for investigating problems in the semi-classical manner and for exhibiting the relation between classical mechanics and quantum mechanics is the Heisenberg Uncertainty Principle. Essentially, the uncertainty relations show



A diagram of the orbit of an electron as based on classical theory

to what extent meaning may be attached to classical concepts like the energy or momentum of a particle in quantum-mechanical problems. We shall write down the uncertainty relation and then explain what the terms in it mean. Any pair of canonically conjugate classical dynamic variables describing a quantum-mechanical system must obey a relation of the form

$$\Delta P \cdot \Delta Q \sim \hbar \tag{1}$$

where ΔP stands for the root-mean-square deviation of P from its average value, and similarly for Q. $2\pi\hbar$ is Planck's constant, 6.2×10^{-27} erg-sec. Canonically conjugate variables are pairs of variables that bear to each other a relation similar to that between pressure and volume in a thermodynamic system. For atomic systems, the most important pairs are momentum and position, and energy and time.

The uncertainty relation (1) can be derived from very fundamental quantum-mechanical considerations. It is the mathematical expression of the fact that in general one cannot specify exactly the values of all classical parameters describing a quantum-mechanical system.

The use of the uncertainty relation in the discussion of atomic systems is best illustrated by a few simple examples. We consider first the well known phenomenon of the scattering of a beam of electrons by an aperture. In Figure 1 consider a collimated beam of electrons travelling toward the aperture with momentum p_x. By a collimated beam we mean a beam for which the velocity in the Y direction is zero. The canonically conjugate variables p_y and y, where p_y is the momentum in the y direction obey the uncertainty relation

$$\Delta p_y \cdot \Delta y \sim \hbar \tag{2}$$

Now if an electron is to pass through the aperture its position on the Y axis must be determined within a distance $y=d$. Therefore its momentum p_y must be indefinite to the extent

$$\Delta p_y \sim \frac{\hbar}{d} \tag{3}$$

If the initial momentum of the electron in the x direction is p_x it follows that the uncertainty in the direction of the electrons emerging from the aperture is

$$\Delta\theta = \frac{\Delta p_y}{p_x} \sim \frac{\hbar}{p_x d} \tag{4}$$

We would thus expect that the beam of electrons emerging from the aperture would occupy an angle of the order $\hbar/p_x d$. Exact quantum-mechanical treatment of the problem shows that actually a diffraction pattern would appear consisting of a central spot and surrounding rings. The size of the central spot, into which most of the electrons go, is of the order of magnitude which we have found.

The experiment which we have just described has figured in discussions on whether or not quantum mechanics conflicts with causality. If the collimated beam consists of a single electron, then it is impossible to predict in precisely what direction the electron will move after passing through the aperture. This has been cited as a violation of causality. Actually, there is no conflict, as is easily seen by a second application of the uncertainty relation. In order to collimate the electron beam it is necessary to fix p_y exactly. The uncertainty relation (2) then shows that the position of the electron along the y axis is completely indeterminate to start with. Thus we cannot expect to predict the precise behavior of the electron after it passes through the aperture.

This brings out another interpretation of the Uncertainty Principle which states that every measurement on a system creates a fundamental disturbance in the system. Thus if we have an electron whose momentum is known exactly and try to determine its position, the second measurement disturbs the momentum of the electron and renders the first measurement invalid.

As a second example we shall consider the emission of light by an atom. According to quantum theory, electromagnetic radiation is composed of particles called quanta or photons. These entities differ even more strongly from classical particles than do electrons. Quanta are particles of definite energy which is related to the frequency of the radiation by the well-known relation,

$$E=\hbar\omega \tag{5}$$

The uncertainty relation allows us to relate the line-width of spectroscopic lines with the time required for the emission of a photon by an atom. Energy and time are canonically conjugate variables and obey the relation

$$\Delta E \cdot \Delta t \sim \hbar \tag{6}$$

Thus, if the emission process takes a time Δt,

$$\Delta E \sim \frac{\hbar}{\Delta t} \tag{7}$$

and the associated line-width due to emission time is of the order

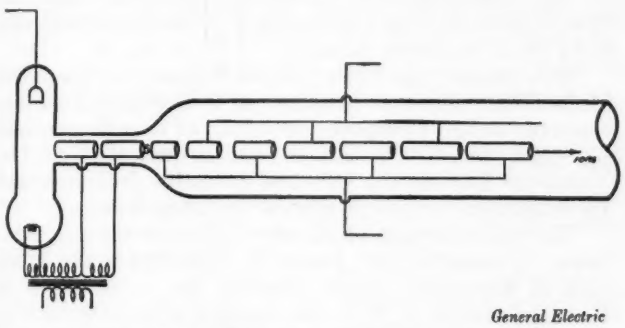
(*Continued on page 220*)

Particle Accelerators

By LEO SARTORI, '50

THE purpose of all particle acceleration is to obtain a beam of high-velocity, high-energy missiles, which are then used in atom-smashing, to generate x-rays, etc. Recently the physicist has been calling for projectiles possessing higher and higher energies, with which he hopes to overcome the huge attractive forces which hold together a nucleus. In order to supply these high-energy projectiles, larger and more powerful models of the existing accelerators are being constructed, and new machines are in the process of being devised.

All the present-day particle accelerators stem more or less from the cyclotron, and this in turn originated from the Sloan-Lawrence linear accelerator of 1931, which was just about the first machine of its kind. The linear accelerator consisted of a long, evacuated tube with a series of cylindrical electrodes situated along its



General Electric

A diagram of the Sloan-Lawrence linear accelerator in which charged particles received impulses as they successively crossed the gaps between the series of tubes

axis. Alternate cylinders were connected to opposite sides of the output of a high-frequency oscillator, thus making the first electrode positive while the second was negative, and so on down the line. Protons (or other positively-charged ions) produced in an adjoining tube were introduced near the first electrode, and when this electrode became negative it would attract the ions to it. Just when the ion arrived at the end of the first electrode, the polarity of the circuit would change, and the ion would be repelled by the first cylinder and attracted towards the second. In this manner, the ion would be accelerated along the tube and would emerge with a fairly high velocity, depending upon the length of the tube, and the voltage of the oscillator. The energy achieved by this machine was about two mev (million electron-volts).

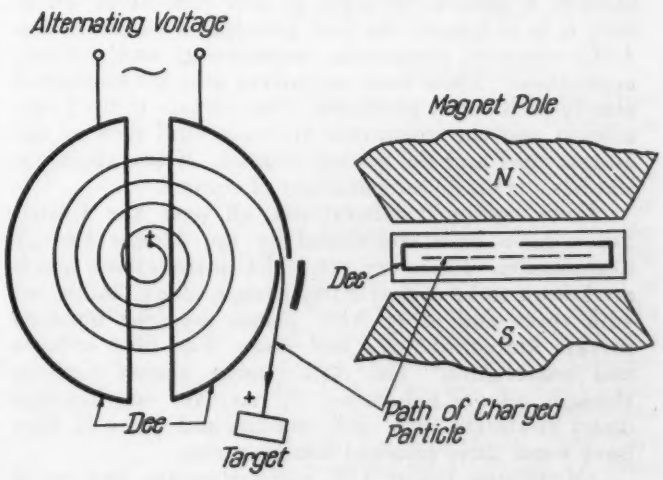
The fact that the energy imparted to a particle did depend upon the length of the instrument placed a definite limitation on the linear accelerator. However, Dr. Lawrence saw that this limitation could be avoided by twisting the accelerator around into the shape of a spiral, and making the particles travel around past the same pair of electrodes again and again. The result was the cyclotron, which consists of two D-shaped electrodes placed close together as shown in the diagram with an evacuated space in between. Ions released in the center of the evacuated chamber are accelerated while they are crossing the space between the dees, and are then forced by a magnetic field to move in a circular path. By the time the ion has reached the gap again (180 degrees further along), the polarity of the electrodes has changed, and the ion is accelerated towards the other dee. Then it travels in a circular path again (this time with slightly larger radius due to its increased energy), and the process continues until the ions reach the outside of the chamber, where they emerge through an opening provided for the purpose. The projectiles used in the cyclotron consist of protons, deuterons, or alpha particles.

For a long time the only improvement made in the cyclotron was to enlarge it more and more, and increase the strength of the fields. However, a new problem eventually arose, which threatened to place a definite ceiling on the energy of the particles ejected by the instrument. This problem was the increase in mass of the ions, due to relativistic effects at high velocities. The entire operation of the cyclotron depends on the fact that, as long as mass and charge remain constant, the period of a particle moving in a circular path in a magnetic field remains constant, no matter what the radius of the path is. However, when the cyclotron projectiles reach a velocity at which their mass is appreciably increased by the relativistic effect, they begin to lag behind and fall out of step with the oscillation of the circuit, the ions arriving at the dees too late to be accelerated. At 200 mev, for example, a proton has forty-three per cent of the velocity of light, and its mass has increased by about ten per cent as a

(*Continued on page 216*)

This diagram of a cyclotron shows how a positively charged particle starts at the center and follows a circularly curved path between the faces of a magnet passing alternatingly from one dee to the other

General Electric



The Atomic Energy Commission

By JERRY B. LEVINE, '51

THE Atomic Energy Commission is in charge of all American research, raw materials, and production in the nuclear field. It has both the money and the authority to support institutional and individual research in this field. By the Atomic Energy Act, "The common defense and security . . ." of America is ". . . the paramount objective . . ." of the Atomic Energy Commission.

The AEC is of necessity a socialized project. The government has complete control over the whole industry, over anything connected with atomic activity. Manufacture of fissionable materials is a complete government monopoly. All patents previously existing in this field have been cancelled and no more are to be granted. Dealings in uranium or thorium are dependent on a license from the AEC. Private use of atomic energy is legal only if the commission grants a license for it. In other words, the application of nuclear technology to industrial processes is completely controlled by the Atomic Energy Commission.

More specifically, the AEC must concern itself with five major tasks. Firstly, it controls all research in pure nuclear science. The real nature of the atomic nucleus is still unknown and will remain so until much more extensive laboratory work has been done.

Secondly, the AEC obtains fissionable materials and uses them in the development and production of atomic weapons. It has as one of its goals increased efficiency of production and increased effectiveness of weapons.

Thirdly, the AEC is conducting research on the industrial use of atomic power, in ships and airplanes as well as manufacturing plants.

The Commission is also concerned with the study and treatment of disease with the aid of atomic knowledge. Radioactive isotopes have proven quite useful in the treatment of cancer and may soon be used against other diseases. A program of research into plant life processes is also being carried out.

The whole AEC organization numbers 45,000 and its members are scattered throughout the country. The five-man commission which heads AEC functions almost entirely on a high-policy level. It makes fundamental decisions on atomic problems and passes them down through a general manager to four executives whose duty it is to control the four principal divisions of the AEC: research, production, engineering, and military application. These four executives also are concerned mainly with policy problems. Subordinate to the Commission and the executives are such staff men as the budget chief and the general counsel. Below them the emphasis is on decentralization of control.

Fully equipped laboratories all over the United States have been established by the Atomic Energy Commission. There are nine AEC installations which are known to be of major importance today. Affiliated with these and other AEC plants are four hundred private industrial firms and more than fifty colleges and universities. The AEC works almost entirely through private industries. It has over one hundred direct contracts with such conerns and these in turn have some three hundred subcontracts.

Of the nine major AEC establishments, five are of extreme importance. Fundamental research is being carried out at Brookhaven National Laboratory on Long Island. More advanced research in atomic piles is conducted at the Argonne National Laboratory in Chicago. Plutonium is produced at the Hanford plant. At Oak Ridge, U^{235} is separated from uranium, and isotopes are produced and shipped to scientific and medical institutions. At Los Alamos the atomic bomb is assembled.

The five men who control this nation-wide organization have various backgrounds. The chairman, David E. Lilienthal, was head of the Tennessee Valley Authority. Dr. Robert F. Bacher is a nuclear scientist from Cornell who helped assemble the first atom bomb. William Waymack was editor of the Des Moines *Register and Tribune*. Sumner Pike, a government administrator, was a member of the Securities Exchange Commission, while Lewis Strauss was an admiral in the United States Navy and a partner in a New York banking firm.

The commissioners' terms all expire on July 31, 1948. They may be reappointed. New terms will run from three to seven years.

The general manager, Carroll Wilson, is a graduate of the Massachusetts Institute of Technology and was assistant to Dr. Compton, president of that institution, for eight years. He also served as assistant to Dr. Vannevar Bush in the Office of Scientific Research and Development, which produced the atom bomb.

The four division chiefs also have diverse qualifications. A scientist, Dr. James B. Fisk, heads the Division of Research. Roger Warner, Jr., a graduate of Harvard and M. I. T., is the director of the Division of Engineering. Col. Walter J. Williams is in charge of production; and a Rhodes scholarship West Point graduate, Brig.-Gen. James McCormack, heads the Division of Military Application.

The Atomic Energy Commission, with all of its control over scientific, industrial, and military groups, is nevertheless responsible to and in close contact with other powerful organizations. The War Department has established an Armed Forces Special Weapons Project which is constantly in touch with the AEC. The Military Liaison Committee is the link between the commission and the Army, and keeps itself informed of AEC's activities. A General Advisory Committee of nine civilian technicians and scientists headed by Dr. Robert Oppenheimer keeps the commission under constant surveillance. The AEC is responsible to the State Department as well as the Joint Congressional Committee on Atomic Energy. It must receive the approbation of two Congressional appropriations committees or it will be faced with a lack of funds. Each of these supervisory groups serves as a check to the overextension of the power of the AEC.

The Commission has been in operation for a year. In that time it has almost completed the job of staffing all of its subsidiary units and contract agencies. The dimensions of its assignment have been set and operational procedures mapped out. The Atomic Energy Commission is well on the road to one of the most important scientific undertakings in the world, the control of the entire nuclear field in the United States today.

The Application of Nuclear Energy to Power

By JOHN W. WEIL, '48

NUCLEAR energy has proved itself to be a miraculous new source of power. But the problem of adapting this source of energy to more peaceful tasks than producing explosions has yet to be fully solved. In order to find such a solution it has become necessary to discover a way to convert the energy produced in fission into some conventional and directly useful form. While several schemes have been proposed to accomplish this end, only a few of them have so far shown any promise of becoming fully practicable. For an understanding of the difficulties involved in the general problem, it might be well to examine the basic facts and then touch upon some of these schemes, dwelling at some length upon the more promising ones.

The source of power in a nuclear reactor is, of course, the fission of a heavy nucleus, presumed for convenience in this article to be uranium, although plutonium and thorium also make good nuclear fuels. Every time one of these fissile atoms splits, about 200 million electron volts — about 3.2×10^{-4} ergs or about 8.9×10^{-18} kilowatt-hours — is given off as energy in one form or another. This then is the energy we are attempting to harness.

Unfortunately, however, this tremendous amount of energy does not originate in a convenient form. The energy per fission is divided up as kinetic energy among the various radiations as shown in the following table of average values:

Particle	*Mev*	*Per Cent of Total Energy*
Fission fragments — FF	160	80
Neutrons		
Prompt	4	2
Delayed — from FF	.008	.004
Gamma Rays		
Prompt	4	2
Delayed — from FF	6	3
From neutron absorption	8	4
Beta Rays — from FF	6	3
Neutrinos	12	6
	200 Mev	100%

The first thing we are forced to note about this table is the large percentage of the fission energy which is carried by neutrinos. Since neutrinos certainly are not confined within the finite limits of any reactor — nor for that matter are they even terrestrial — we can immediately regard their 12 Mev as lost. Thus before we are even started, we have cut ourselves down to 188 Mev per fission.

If we next consider the range of the various radiations we will find that the fission fragments, being large and heavily charged, are stopped almost at the point of fission and, consequently, that the beta rays — which originate from the fission fragments and which are very short ranged particles themselves — will also concentrate about the point of fission. Thus 166 Mev, 83 per cent of the total, are dissipated to the surrounding media at the location of the original nuclear explosion. The neutrons on the whole will expend their energy throughout the reactor in causing further fissions, in being captured, or, if the reactor is not a fast reactor, in slowing down. Similarly, the gamma rays will spread their 18 Mev throughout the reactor, but will also take some of this energy outside of the confines of the reactor proper as the more powerful gamma rays penetrate the reflectors and shielding.

Figure 1. Nuclear powered pseudo-rocket

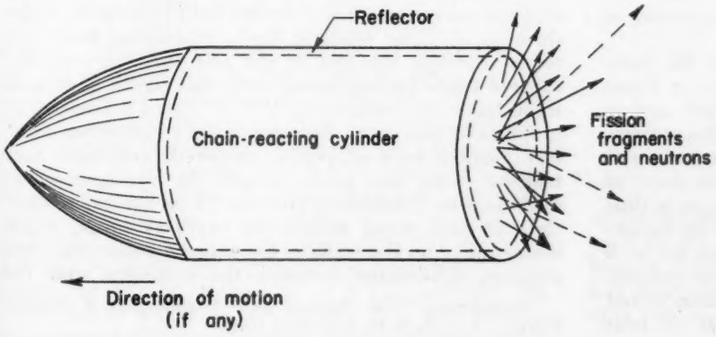
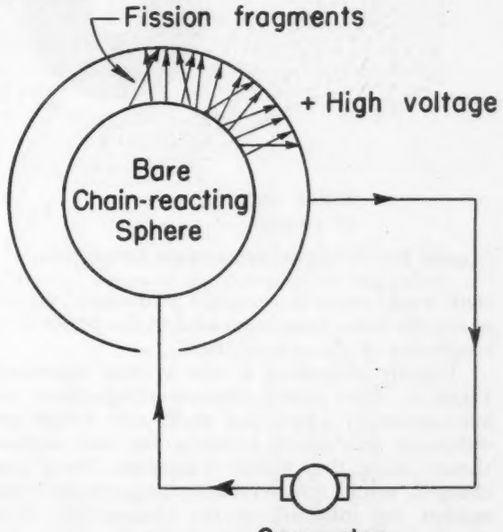


Figure 2. A hypothetical method of obtaining a fission EMF



Thus we see that the majority of the energy we are trying to control becomes dissipated in the fissile material and is thus available to us only as energy of motion of those particles extremely close to the point of fission. In other words the fission energy from a present-day type of reactor becomes available only in the immediate vicinity of the fissile material, and only then in the form of heat. A present-day reactor thus is only a new

kind of heat source, but one capable of producing tremendous quantities of heat at temperatures limited only by the engineering materials which must contain the reactor. This last point is an important one to remember, because many of the limitations of the schemes we shall discuss are due to inadequacies in the engineering materials other than in the reactor itself.

To begin with, let us consider the nuclear "powered" projectile shown in Figure 1. This is merely a nuclear reactor surrounded, except to the rear, by a reflecting material. The principle of conservation of momentum states that as the fission fragments, neutrons, etc., are allowed to escape to the rear the projectile will move forward. The idea is quite naturally absurd. To begin with, as we have already seen, only those fission fragments from the very thin layer of reactor at the extreme rear of the projectile would escape. Furthermore, these fragments would not be able to penetrate any skin placed over the rear of the projectile — and in any engineering case, such a skin would be necessary. As a final blow, even if a considerable number of fragments did penetrate the rear of the projectile, the momentum

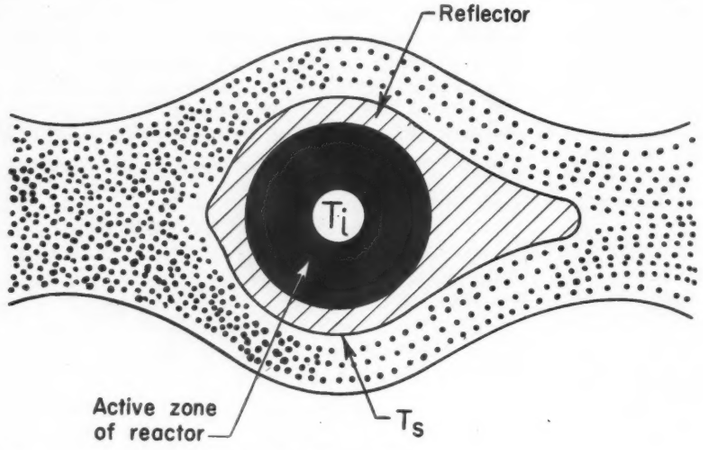


Figure 3. A hypothetical ram jet engine

they would carry is certainly of doubtful significance, to say the least, when compared to the decidedly macroscopic size of the reactor itself.

Equally ridiculous is the system represented by Figure 2. Here a bare, chain-reacting sphere would be surrounded by a spherical shell, with a high potential difference established between the two surfaces, the theory being that fission fragments, being positively charged, would transfer their charge to the outer shell against the influence of the electrostatic field, thus creating a current. Quite obviously, the power produced would be painfully small even if we could decide that the fission fragments would reach the outer shell in any considerable number, which we have seen is certainly impossible.

Not quite so immediately preposterous is the ramjet engine shown in Figure 3. Here smoke or other particle-laden air enters the jet from the left and is heated by radiation from hot surface T_s of the streamlined reactor in the center of the jet. The air molecules adjoining the smoke particles rapidly receive most of the energy captured by the smoke, and the air is thus heated. This heated air is forced to the rear by incoming cool air and thus leaves the rear of the jet at a higher velocity because of its greater heated volume. The difficulty here is principally that radiation is not nearly so important as are other methods of heat transfer at the upper limits of temperature imposed by present engineering materials. Such a device would probably not operate on the more promising principles of convection or conduction because of the necessarily small surface areas dictated by the fact that large surface area in a reactor would mean similarly large leaks in the neutron flux and a consequent increase in the volume of the reactor in order to maintain criticality.

Because a pile is a good source of extreme temperatures and because electricity is one of the desirable forms in which to produce energy, the principle of the thermocouple suggests itself. Certainly, while large currents might be produced, the voltage would be trivial indeed if ordinary thermocouple procedures were used. Further possibilities involving unconventional uses of the thermocouple principle might be investigated, but the possibilities can best be summed up as unknown.

One of the most intriguing bits of speculation about nuclear power adaptations put forth so far has been proposed by Professor Hsue-Shen Tsien of the M.I.T. Aeronautical Engineering Department, who has proposed a method for using a nuclear reactor to propel a large rocket. It can easily be shown that maximum final velocity for a rocket can be obtained by maximizing the exhaust velocity of the propellant. In order that this condition may be reached, relativistic considerations demand that the propellant be as light as possible. Photons are obviously out of the question, so some gas such as hydrogen — which would effectively consist of protons — might well serve as the propellant. Since engineering materials are characterized by their molecular nature, we must stay at temperatures which would not disrupt the molecular bonds, and thus cannot begin to approach the tremendous temperature needed to attain the theoretical maximum for the exhaust velocity of such a propellant as hydrogen. However, by making an engineering compromise, a plausible solution can be found. If we use a normal variety of nuclear reactor as our heat source and establish our maximum working temperature at about 3300 degrees Absolute or 6000 degrees Rankine, we may begin to form a picture of our rocket motor. Unlike the thermal jet proposed above, we shall use conduction as our principal method of heat transfer.

Figure 4 shows Professor Tsien's proposed rocket motor. It would consist of a cylindrical, thermal reactor controlled by an absorbing control rod inserted along its axis. The control rod might be cooled by making it of porous cadmium and forcing cold hydrogen axially through it. The working fluid, hydrogen, would be forced through the rest of the pile through conically tapered tubes having porous walls one eighth of an inch thick made of a mixture of U^{235}, U^{238}, and a moderator, graphite in this case. Because of the tremendous effective surface area of porous material, sufficient heat transfer could take place to heat the hydrogen up to 6000 degrees Rankine. Professor Tsien has calculated* that at each point within the capillary tubes, which would make up the walls of the tapered tubes, the temperature differential between the hydrogen and the

* Goodman, "The Science and Engineering of Nuclear Power," Vol. II, to be published soon.

solid wall of the capillary tube would be on the order of 120 degrees Fahrenheit. He has further shown that the pressure drop along the length of the capillary tubes, that is, the pressure drop across the walls of the tapered tubes would be about two pounds per square inch, quite a reasonable value. From this, Professor Tsien has gone into further calculations, too lengthy to reproduce in the space available here, and has calculated the characteristics of the thermal reactor which might be used in such a rocket and has combined these results with the above values and dimensions to get the following sample results. Certainly while the rockets would not be playthings, these sample results are intriguing.

	Example I N(235)/N(238) $= \frac{1}{10}$	*Example II* N(235)/N(238) $= 1$
Diameter of pile, inches	191.4	150.4
Length of pile, inches	95.7	75.2
Weight of active material, tons	33.6	16.33
Weight of U^{235}, lbs.	120	190.2
Weight flow of hydrogen, lbs. per sec.	6,980	3,360
Thrust, tons	2,600	1,251
Energy rate, Btu per sec.	1.505×10^8	0.726×10^8
Kw	1.59×10^8	0.765×10^8
Initial weight of rocket, 60% of thrust, tons	1,560	751
Weight of hydrogen carried, 48% of thrust, tons	1,246	601
Duration of burning, seconds	358	358
Total amount of heat generated, Btu	5.39×10^{10}	2.60×10^{10}

The difficulties with the actual engineering of Professor Tsien's rocket are principally involved in producing tapered tubes whose porous passages would be sufficiently clear to allow a maximum flow of hydrogen. It might also be pointed out that by using an epithermal or fast reactor, the critical size of the reactor, and thus the size of the rocket, could be greatly reduced. Furthermore, the suggested use of porous materials for heat transfer could also be adapted for use in a nuclear ram-jet with good success. It is also assumed throughout that the nuclear rocket would be expected to operate for reasonably long periods of time — about a minute or greater — for below this limit conventional chemical fuels are often more economical.

We have seen that hydrogen forced through porous reactor materials might be used to remove the heat-energy from a nuclear plant, but we have also noted that such a system is not yet within our immediate reach. Suppose, however, that we were to circulate our working fluid through the reactor much as we would circulate a coolant through a conventional furnace or motor. We could then remove the heat from this circulating fluid by means of a heat exchanger and use it to produce steam for turbines or other similar applications. This, in its barest form, is the present-day power pile.

We presumably know by now that all nuclear reactors are activated by neutrons cycling between fissions. If these neutrons, which are produced at energies of about one or two Mev, are slowed to the thermal region — about .025 ev — before they cause fission in a particular reactor, then the reactor is known as a thermal reactor. If the neutrons cause fission principally in the range of a few electron volts, then the neutrons are cycling in the resonance or epithermal region, and the reactor is known as a resonance or epithermal reactor. In the case where the neutrons produced in fission are used directly to produce further fission, the pile is referred to as a fast reactor. An atomic bomb would be one variety of a fast reactor. The principal difference between the actual components

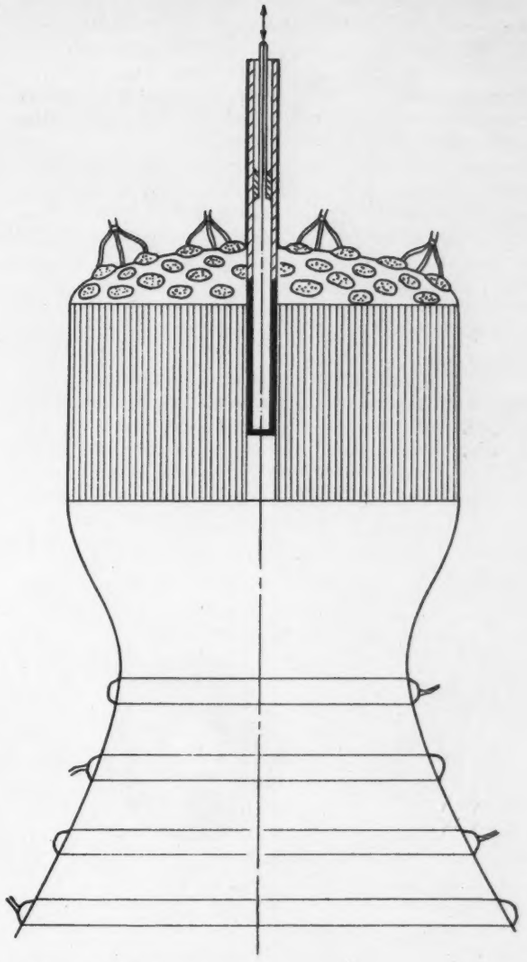
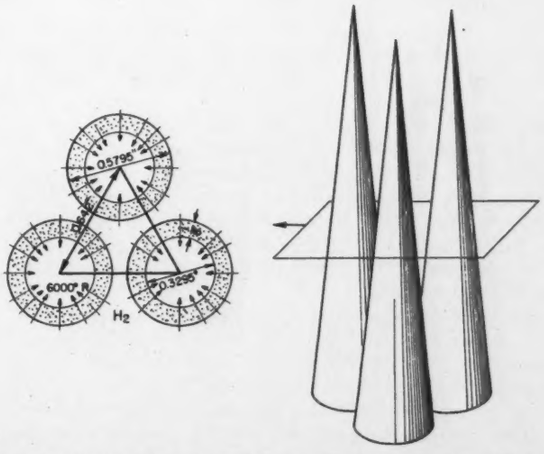


Figure 4. Schematic diagram of proposed rocket motor showing three of the conical porous tubes



of the three kinds of piles lies in the nature of the diluent used in the uranium. A fast reactor may or may not require a diluent — since no slowing-down is needed — but both resonance and thermal piles must have diluents whose principal function is to moderate the

(*Continued on page 210*)

An aerial view of a pilot plant at the Clinton Engineering Works
Manhattan District

THE TECH ENGINEERING NEWS

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From the Editor's Notebook

Ralph Johnston has been working on the *T.E.N.* in the make-up and literary departments since he came to M. I. T. in the fall of 1946 as a student of aeronautical engineering. Previous articles include one on a steel mill and one on a radio hams' convention. Ralph hails from New Kensington, Pennsylvania, where he had lived all his life prior to coming to Tech.

Though only a freshman here at M. I. T., **Ken Kopple** is a veteran writer for the *T.E.N.* His first article appeared last December and was followed shortly by another in the February issue. The latest piece of work on radioactive isotopes tops off his previous efforts and shows how correct Westinghouse was in selecting Ken as one of the forty winners in their 1947 Science Talent Search. Ken's home is in Elkins Park, Pennsylvania, and as you might guess, he plans to study chemistry here at M. I. T.

As mentioned above, **Jules Levin** is one of the students taking Professor Goodman's course. Jules was graduated from high school in Miami Beach, Florida, in 1944 and thereupon came to M. I. T. as a student in the engineering option of its General Science Course. His outstanding academic work led to his election to Tau Beta Pi, honorary engineering fraternity, and at present he is vice-president of M. I. T.'s chapter. Now in his senior year, Jules has been taking all the courses he could in the field of nuclear engineering, and he plans to be one of the country's first nuclear engineers.

Bob Kraichnan, born Robert only twenty years ago, already holds a Bachelor's degree from M. I. T., has taken and passed his doctoral exams in the graduate physics school, and is now engaged in research for his Doctor's thesis on Quantum Electrodynamics. Bob also comes from Elkins Park, Pennsylvania, a place that seems to be sort of a breeding place for scientific talent. In his undergraduate days, Bob was a vice-president of the M. I. T. Rocket Society and worked on the *T.E.N.* staff; even now, he still joins in every once in a while with the M. I. T. Symphony.

Leo Sartori was graduated from Stuyvesant High School in New York City in June, 1945 but waited a year before coming to Tech to start studying physics. Leo is taking as much math as is possible with hopes of directing his attention toward theoretical physics. As a freshman, Leo wrote a story for *T.E.N.* on Food Technology; however, academically, he did not wander far and at the end of the year, he was awarded the Freshman prize in mathematics.

Jerry Levine arrived at M. I. T. only last September, determined to study something serious. From the fair city of Chicago, Jerry had attended the High School and College of the University, and with this background, decided to take up Engineering and Business Administration. This won't be the last time, either, that you'll see Jerry's name on these pages. He has already been assigned a couple more articles and if he

(*Continued on page 222*)

The Dragon's Den

Let's Be Practical . . .

Whether or not the United States has universal military training in the coming years is of great significance to students everywhere. Still, it would not be very broad-minded to consider the issue on the basis of who will be subject to call under this training program. Nor is it showing intelligence to ask the proponents of the U. M. T. Bill whether they would be eligible for this form of draft. However, the fact that students who must do graduate work before they can assume an effective role in the field of their profession are delayed one more year, at least, by U. M. T., cannot be overlooked. M. I. T. students either come here for graduate study or are quite likely to do graduate work before their schooling is over. This graduate work delays long enough the day when the young man can start supporting himself and a family at a full-time job. To add another year to the age at which such men can consider setting up a home should not be done lightly.

Many arguments for and against U. M. T. have been put forth. Those for it stress the urgency of being prepared for war. Those against it fear the influence that such training would have on the youth of America.

Even if we should compromise our moral and ethical standards for pressing practical reasons, how successful would U. M. T. be along the lines for which it is designed? How seriously will the training program be taken by those in it? If previous experience serves as good indication of what to expect, then we might well assume that during peace time American youth will not take the Army too seriously and will be inclined to consider military training as a lark. Both pre-war and post-war experience would indicate that we could look for the attitude that military life is really a big picnic. There is even reason to doubt whether the military will take the program seriously.

Perhaps we can rejoice that the American youth are not militaristic and do not readily fall into a life of strict obedience. But why encourage them to disobey and goldbrick whenever they can manage to do so? There are many more efficient methods of protecting the nation. An economy-minded Congress ought to realize that the general youth drafted for a training he does not want will not make as much effort to see that the government gets any defense benefits out of the money it spends as the engineer or scientist will if given the money to work on weapons. We certainly do not call for further effort in looking for deadly weapons. But no matter how we look at U. M. T., whether as moral or practical men interested in protecting the United States, we can see little good in it.

E. T. M.

Engineer in an Ivory Tower . . .

American scholars have been noted in the past for their ignorance of the "practical" details of the communities surrounding them. This paucity of knowledge has been furthered by the mythical separation between "learning" and "living." Finally, the American student, until very recently, has been for the most part, a Joe College. A peculiar attitude toward knowledge developed with the increase of the bourgeoisie; this attitude reflected itself in the disinterest of students in current affairs and in the fear of many schools that endowment funds would be cut off. So, for one reason and another, a barrier was built up between the student and politics, and current affairs are taboo in many institutions of learning. At Northeastern University, no organizations are permitted which have affiliation outside the campus and the newspaper is censored.

The school has been proclaimed as the rock which stands above events, as the storehouse and laboratory of knowledge. But, if the devotees of the Lamp of Knowledge must entertain political concepts, let them follow in the footprints of those who support the college. It was reported that Will Clayton, Undersecretary of State, conferred with members of the M. I. T. Corporation on policy when he was here recently. Previously, Professor Padelford of the Economics Department had handed out petitions to his students so that they might indicate "support" for the Marshall plan. The rock, indeed!

For years and years, European university students have taken an active interest in political movements. They realize that no matter how monastic one may wish to be, it is impossible to avoid being affected by events in the world around you. On issues of housing, universal military training, war, "un-American activities," good local government, and education, students must at least have some thoughts if not the desire to express their opinions. Private "bull sessions" are fine, but who is going to tell the government what *you* think? It's time, men of M. I. T., that, regardless of political views or inclination, you take an active interest in politics and government, for your sake as well as for the sake of the world.

E. M. K.

HEALTH PHYSICS

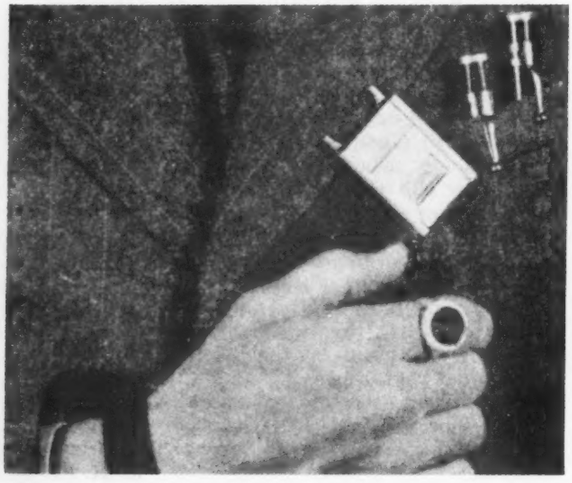
(Continued from page 190)

physical (mr.e.p.). (Because the roentgen is defined in terms of the secondary electron energy produced by x and gamma rays, it was necessary to define a new unit for neutron radiation. The r.e.p. is based upon the physical effect of neutrons on flesh as compared to that of x or gamma rays. Thus, 20 mr.e.p. produces the same effect on flesh at 100 mr.) It should be understood that the term tolerance level refers to the maximum permissible dose of radiation a person can receive safely per unit time. At the Clinton National Laboratories, no one has yet averaged over ten mr. per day while employed there. Such a low average is to be desired, for there is some reason to suspect that human beings should not receive over 1000 r. in the male and 100 r. in the female during their lifetime if the additive effects of radiation are not to shorten the life span of the individual.

Once radiation tolerance levels were established, the Research and Development group had to develop instruments for use in checking radiation exposure. A variety of instruments were designed, but basically they are all modifications of devices such as the fiber electroscope, the Geiger-Mueller counter, the x-ray film, and the ionization chamber.

The most reliable survey instrument is the Landsverk-Wollan or Lauritsen types of fiber electroscope. These instruments are used for quantitative examination of radiation because they are sturdy and maintain their calibration for long periods of time. Such instruments are used to check all laboratory areas and outgoing packages. Geiger-Mueller tubes are used in many forms as indicating instruments. Their forms range from small hand units designed to be carried by one man to a large instrument called the fourfold hand counter used to measure the irradiation of a person's hands and feet. The fourfold counter is a cabinet, about five feet high: the man to be checked stands on a platform in front of the cabinet, placing his hands in two openings. In 24 seconds the counter takes a complete radiation count on the person's hands and feet. Geiger-Mueller tubes are often placed in groups around door frames to sound a warning if any person going through the door has radioactive material on his clothing. Geiger-Mueller tubes are also used to check the radiation in the air in the plant area. These air monitors automatically keep a paper record of the radiation levels of the air.

This man is well guarded against unnoticed radiation with ion chambers in his lapel pocket, a film badge on his lapel, and also a ring and a wrist meter



One of the simplest yet most important devices used by the health physicists is the film meter. The film meter is a small lapel badge containing an ordinary dental x-ray film, part of which is covered by a cadmium shield. The blackening of the film under the cadmium is proportional to the total gamma ray exposure. The blackening of the unshielded portion of the film is proportional to the exposure to beta rays or soft x-rays. A special neutron sensitive film is worn by those who work in areas of neutron radiation. Meter film can also be worn in finger rings and wrist straps. Another interesting personal meter is the pocket dose meter. About the size of a fountain pen, the pocket meters are of two types. One is a small air condenser which is charged before exposure and leaks in amounts proportional to radiation received. The received radiation can be measured by discharging the condenser. The other type of pocket meter is a small fiber electrometer which can be read directly.

The responsibility for the use of the above instruments falls on the Personnel Monitoring and Survey groups. Every person entering a restricted area (one with a radiation exceeding 12.5 mr/hr) on the plutonium project picks up a film meter and two pocket meters. Two pocket meters are used to minimize accidental errors of instrumentation. The three meters are carried by the worker during his duties and at the end of the day are returned to a special rack. The pocket meters are examined by the Personnel Monitoring group and if both meters indicate a significant fraction of a day's tolerance exposure, the film badge is read and an investigation made the next day to make certain that no one has been exposed to excessive radiation. All persons working in restricted areas must wear special overalls, hats, gloves, and shoes which are washed at regular intervals in the laboratory decontamination laundry. The laundry uses conventional deturgents to remove dirt and citric acid to dissolve radioactive isotopes. All outgoing garments are checked by Geiger-Mueller counters for activity.

The survey group has as its responsibility the constant checking of radiation levels in the plant area, in waste products, and in outgoing packages. Instruments to monitor the air are scattered throughout the plant buildings and sound a warning if radiation ever exceeds the safety level. The survey group must also continually search for defective shielding around the pile. The solid contaminated waste material from atomic energy plants is buried in guarded areas, and most of the liquid waste is stored in large tanks. Some of the liquid waste is discharged to holding ponds where it is constantly monitored by automatic counters. The liquid waste must be safe for continued use either as drinking water or for swimming. All outgoing shipments of isotopes are checked to see that radiation does not exceed 15 mr/hr at the package surface. This leaves a large safety margin, for United States shipping regulations allow a radiation of 200 mr/hr.

It can be seen that the job of protecting the many workers in atomic energy plants is an enormous one. No one, however, has yet been injured, as far as is known, by radiation at any of the plutonium projects. The field of Health Physics is a rapidly growing one, and as the use of radioactive materials becomes widespread, it will be necessary to find many more people trained in the methods of this new science.

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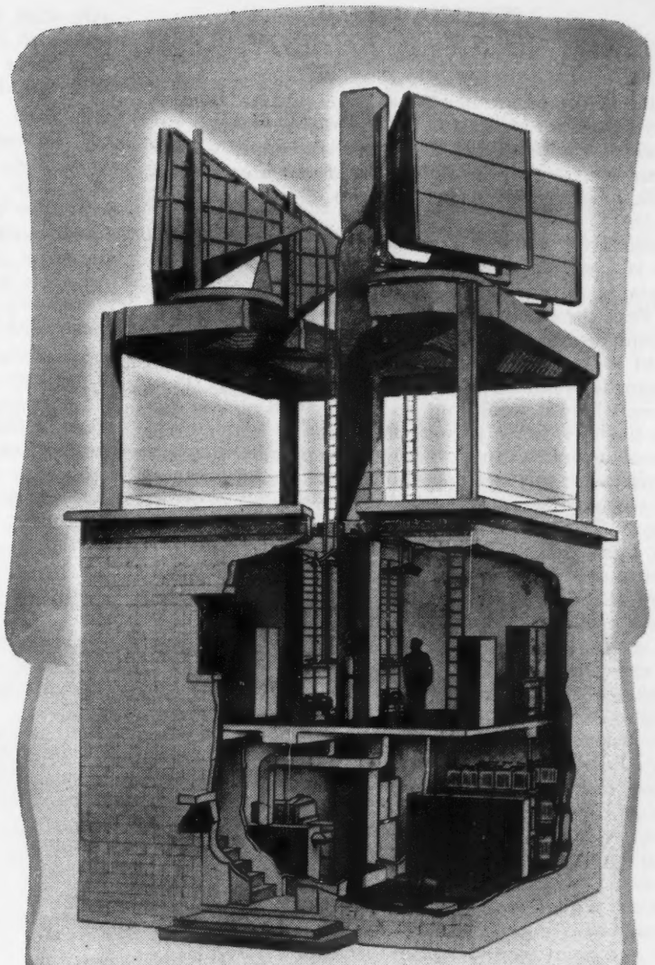
BELL TELEPHONE SYSTEM



A cut-away view of a typical radio relay station. Emergency power equipment and storage batteries are on the first floor, radio equipment on the second floor, and the special microwave antennas which receive and beam the communication signals are on the roof.

APPLICATIONS OF NUCLEAR ENERGY

(*Continued from page 203*)

velocity of the fission neutrons. This diluent, then, is referred to as a moderator. In a resonance reactor the moderator might be such a material as copper while a thermal reactor requires light elements such as carbon, beryllium, or deuterium in the forms of graphite, BeO, or D_2O.

Peculiarly enough, the nuclear properties of matter make it easier to make a reactor critical if the fissile material is not mixed homogeneously with the moderator. Thus the uranium may be in a reactor in the form of lumps or rods surrounded by the diluent.

But we have already noted that most of the heat in a reactor is produced in the fissile material itself. Thus in cases where it would not be practical to remove the pile's heat by using porous pile material and forcing our cooling fluid through, it might be possible to use a heterogeneous mixture of uranium and moderator and merely cool the uranium lumps with some sort of circulating fluid. Figure 5 shows such a nuclear power plant, using a gas coolant.

Of course, there are many variations to the problem. Where the diluent is a liquid — such as D_2O — the diluent could be circulated and used as the primary coolant. Or in a case where the fuel itself was a liquid — such as a solution of uranium — the fuel itself could be made to circulate. This would have advantages from a heat engineering standpoint, but would be difficult from the point of view of safety, since all the heat exchangers and pumps would become badly "poisoned" with radiation. Finally, the fuel and the diluent might be contained in the same solution, such as a solution of uranium salt in heavy water. In such a case the entire fluid could be circulated. This fluid arrangement was used in the famous Los Alamos Water Boiler — although it is not known whether the Water Boiler's fluid was circulated or not. A typical pile with a circulating homogeneous fluid mixture is shown in Figure 6. Variations in the energy distribution of the cycling neutrons as a function of diluents of different atomic weight are shown in the accompanying graphs.

We must mention another point. If natural uranium — 0.715% U^{235} — is used in a bare, homogeneous pile, it can be shown that only a D_2O-moderated reactor could be made critical. Heterogeneous piles can be made critical with other materials. However, if the uranium is enriched in U^{235} content, other materials will also work with a homogeneous set-up. It can also be shown that the size of a reactor can be greatly decreased by using enriched fuels.

Critical size can also be lessened by the use of a surrounding reflector for neutrons, which would tend to decrease the number of neutrons escaping from the reactor material and thus increase the effective neutron utilization. The Water Boiler at Los Alamos made good use of both enriched fuel and a reflector, as is shown by its critical size — a sphere, one foot in diameter.

We can now visualize our nuclear power installation of the future. Presumably it will be a reactor of either cylinderical or cubical form — merely for structural reasons, spheres being hard to build — containing a heterogeneous mixture of fuel and moderator — for easier cooling. It is probable that some material other than the fuel or moderator will be used as a coolant because of the consequent lessening of radiation dangers within the heat exchanger and pumps and because of the scarcity of good fluid moderators. Our reactor will be surrounded with some reflecting material, unless the reactor is designed to be as light as possible for use in some mobile installation — for a reflector may well add weight in spite of the fact that it decreases the amount of fissile material needed. The entire

(*Continued on page 212*)

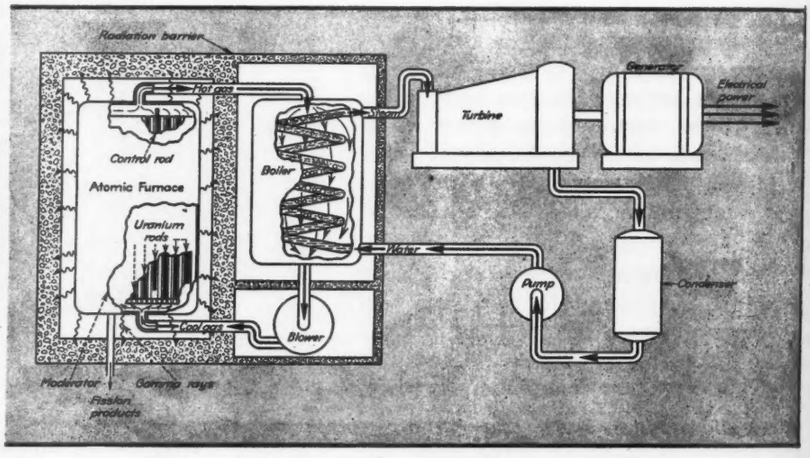


Figure 5. Schematic diagram of projected power installation

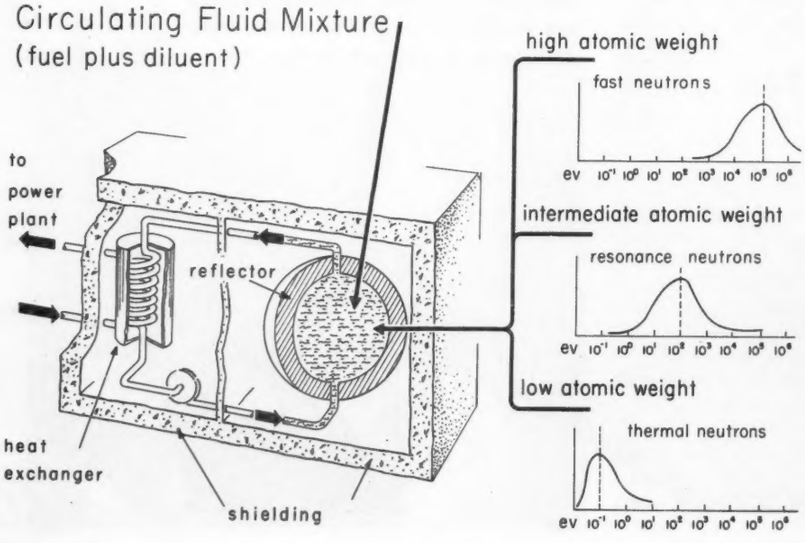


Figure 6
Typical homogeneous pile with circulating fluid mixture

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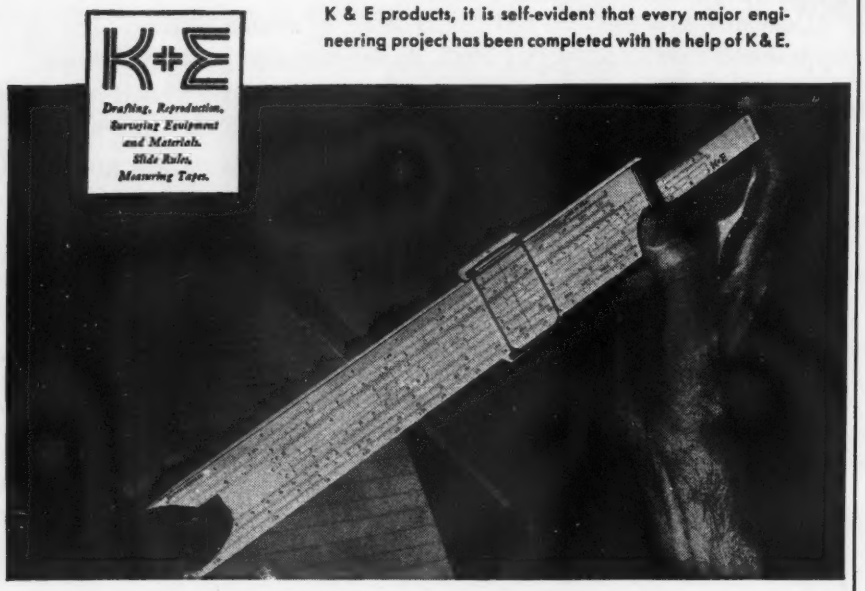

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APPLICATIONS OF NUCLEAR ENERGY

(*Continued from page 210*)

installation will be surrounded with a so-called biological shield of concrete and lead, as well as other metals, in order to keep the health hazards to personnel within the power plant to a minimum. Because this shielding is bulky, it is probable that the thickest shielding will be placed directly around the reactor, with lighter coats around the cooling system, rather than putting a heavy shield around the entire system. A typical shield might consist of a thickness of concrete to slow down fast neutrons, followed by a sheet of cadmium to absorb the neutrons, followed by a layer of lead to stop the primary gamma rays from the pile and the secondary gamma rays emitted by the cadmium in capturing the neutrons. An initial layer of lead might be placed closed to the pile to reduce the cost and weight of the reactor by minimizing the amount of lead needed in the final layer.

Finally, by adding a heat exchanger, pumps, and many controls and monitors, we can complete our picture of the plant. It is also probable that access hatches will be left in the shielding to allow remote control equipment to enter the cooling system or reactor proper to effect repairs or to remove fuel rods for reprocessing. A typical installation of the kind described is shown in Figure 7.

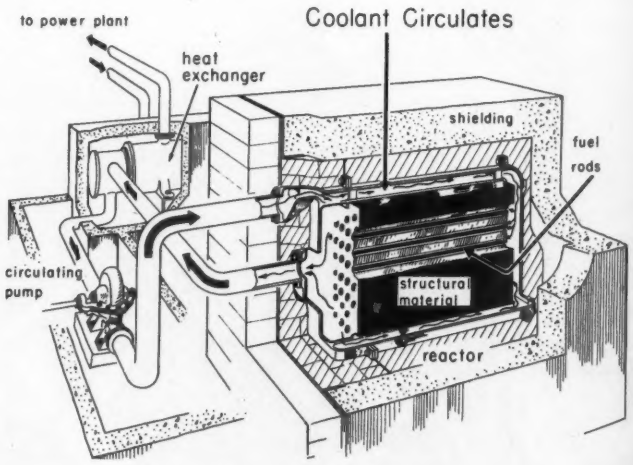
Just how feasible is all this economically? Briefly, estimates have shown that nuclear power will be able to compete with conventional power sources in some localities within the next ten years. Some advantages would be the small amount of fuel needed to replace the "burned out" material, with consequent lower transportation costs for fuel; the smaller size of the installation; and possible higher efficiencies in the operation and production of electricity from the intrinsic point of view of a compact, highly energetic variety of fuel.

A neat point to note is that in resonance or thermal reactors which demand the presence of a material such as U^{235} which is thermally fissionable, the pile might be designed to simultaneously produce plutonium from the U^{238} which inevitably must be present anyway. This plutonium could then be "burned" as further fuel. Theoretically, one hundred per cent of the uranium could be used to produce power. So long as there was U^{238} present in the fuel mixture, the pile could not burn itself out. Whether this will be possible in a practical case remains to be seen.

To date no nuclear reactors have been built with a primary purpose of producing power. There is, however, a considerable demand for the construction of such a plant among scientists in the nuclear field. Because of this the next few years may well see interesting developments along the lines so hazily sketched in this article and great progress may be made towards fulfilling many of the predictions of the Sunday Supplements concerning the great Atomic Age of the future.

Author's Note: All diagrams and much of the material for this article come from Dr. Clark Goodman's "The Science and Engineering of Nuclear Power," Volumes I and II. Volume I has been published this past year, and the material for Volume II has already been declassified and will appear in print shortly. Both volumes are being published by the Addison-Wesley Press, Inc. of Cambridge.

Figure 7. A heterogeneous reactor with solid diluent and circulating coolant as part of a power installation



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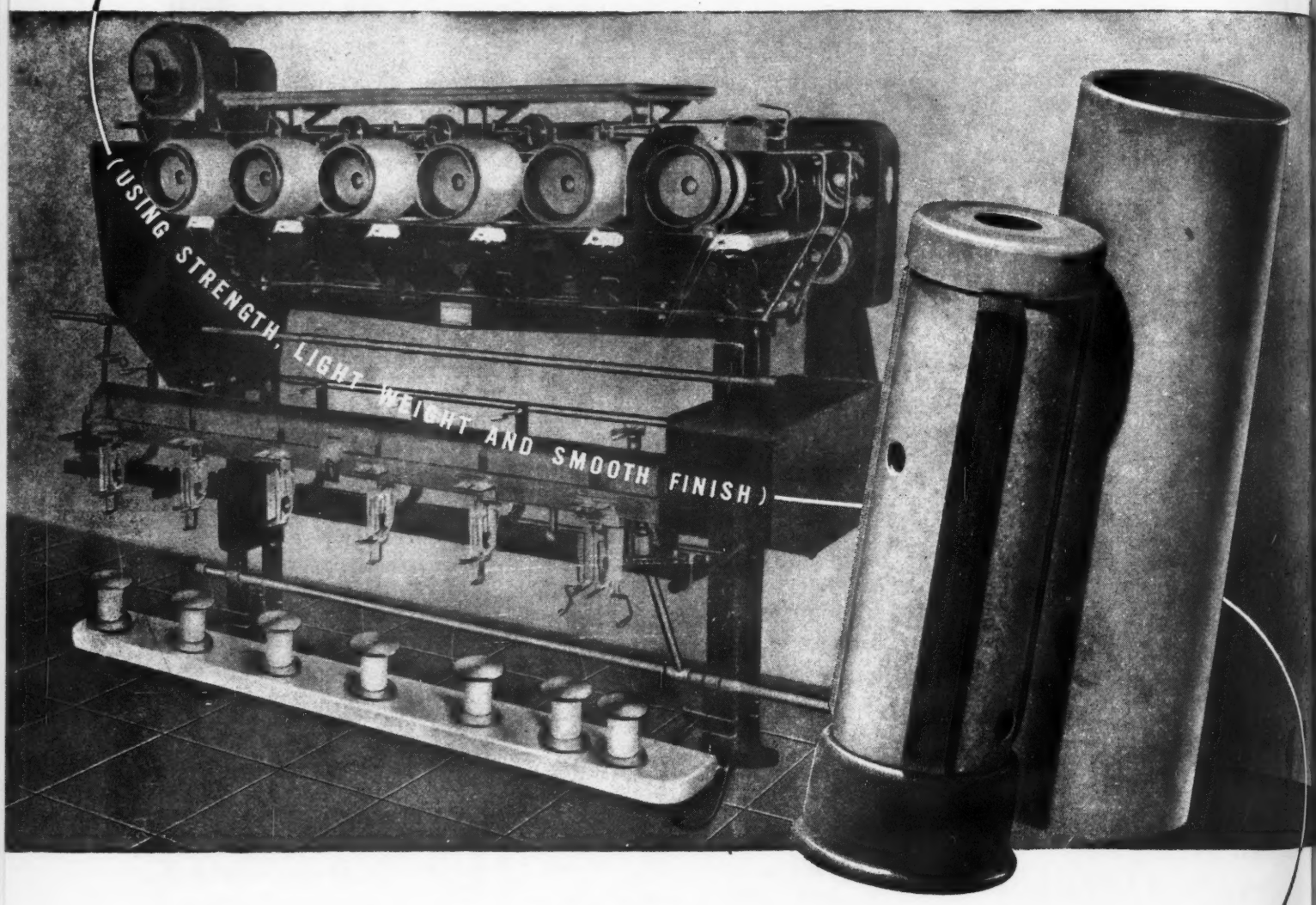

Fine nylon filaments can be wound without pulling and sticking because of the smoothness of the bobbin. Light weight of bobbin and chuck allows the spindle to be started and stopped faster and with less effort. Greater crushing strength of tube permits larger amounts of nylon to be wound. This is an appropriate job for Synthane, an interesting example of using plastics where plastics belong.

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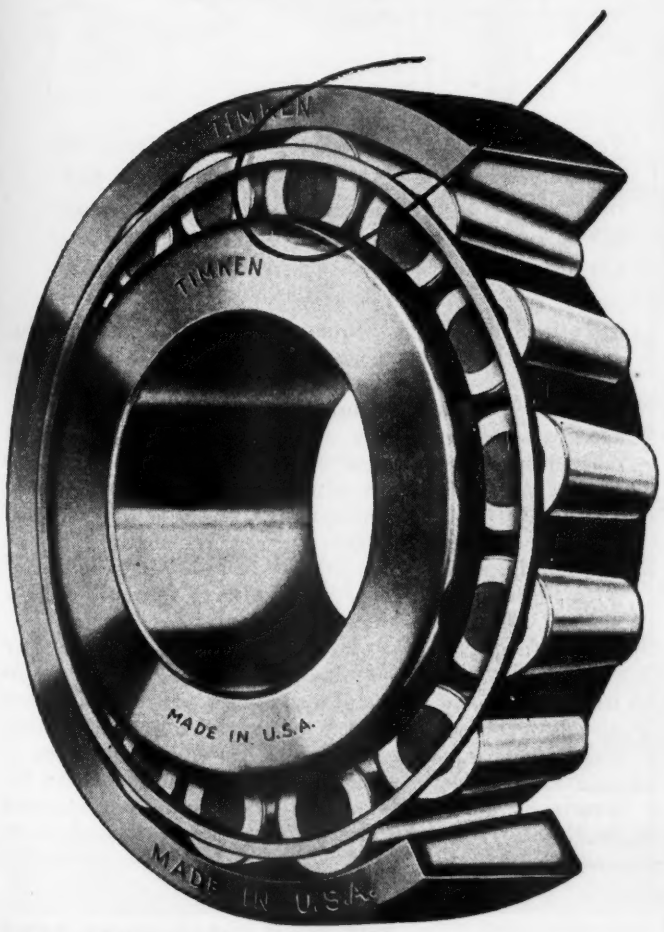

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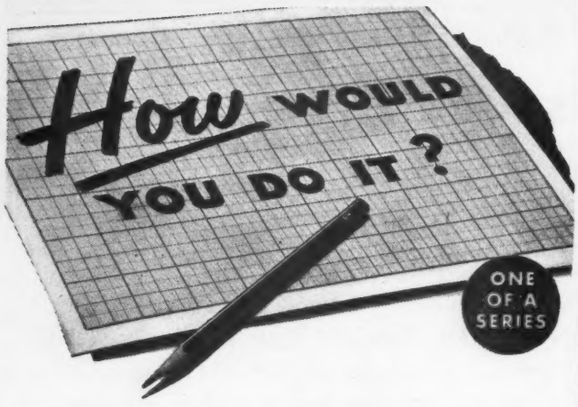

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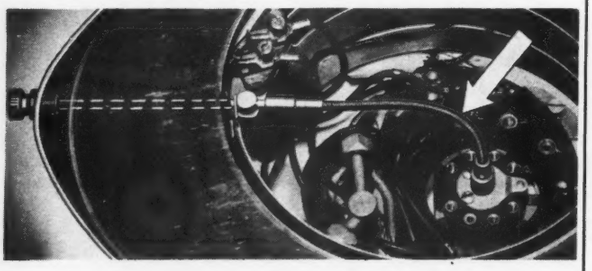

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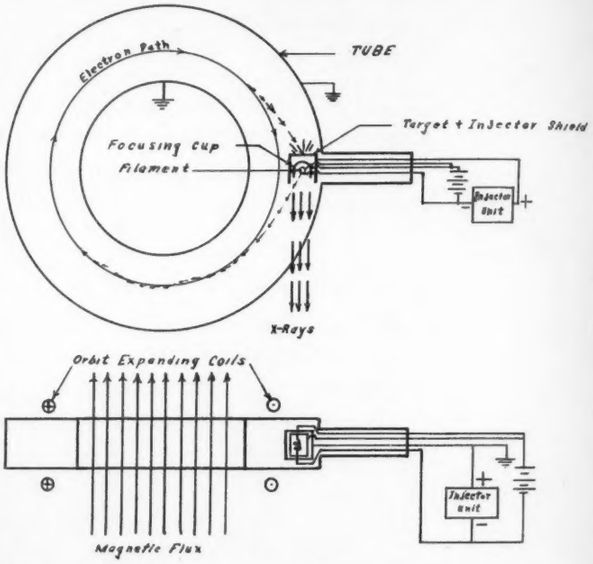
PARTICLE ACCELERATORS

(*Continued from page 199*)

result. Even much smaller increases in mass are sufficient to impair the operation of the instrument. Due to this relativistic effect, the maximum energy possible from an ordinary cyclotron is placed in the neighborhood of twenty mev.

The problem of this limitation was solved by varying the frequency of oscillation of the electric field to keep step with the change in mass, and this improvement was incorporated into the new 184-inch cyclotron at the University of California. The new machine is known as a synchro-cyclotron, or frequency-modulated cyclotron. When the ions start out at the center of the machine, the oscillator is operating at 11.4 megacycles. As the particles begin to lag behind due to their



This sketch of the electron path in a betatron indicates how the electrons start from the filament and follow a circular path around inside the doughnut until they are sent against the target

increased mass, the frequency of oscillation is gradually reduced to ten megacycles, and so the projectiles still reach the edge of the dee at the proper time. Of course, under such an arrangement there cannot be a continuous flow of ions, since the frequency which is correct for those ions near the end of their journey would not be correct for those which are just starting out and are going slower. Consequently, the ions are released in spurts, with about 1000 spurts per second. Energies of 200 million electron volts have already been achieved with this machine, and even as high as 600 mev is considered within its scope.

The accelerators so far discussed all employ as their projectiles the so-called "heavy particles," mainly protons, deuterons, and alpha particles. However, it has also proved useful to have a beam of high-energy electrons, either for direct use or for the generation of x-rays. The first machine to achieve this end was the betatron, sometimes called the induction electron accelerator. The betatron is actually a type of transformer, with the primary being the coil of a powerful

(*Continued on page 218*)

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PARTICLE ACCELERATORS

(*Continued from page 216*)

magnet, and a beam of electrons serving as the secondary. The electrons are accelerated inside a doughnut-shaped, evacuated tube, located between the poles of an electromagnet. Unlike the projectiles of a cyclotron, the electrons in a betatron do not follow a spiral path, but travel around in a circle of nearly constant radius. They are ejected from the hot filament of an electron gun inside the doughnut, and are accelerated tremendously as the voltage in the primary builds up during the first quarter cycle. When the primary voltage reaches a maximum, the electrons are caused to leave their circular path and strike a tungsten target, generating a beam of high-energy x-rays. The electrons also radiate away some of their energy as visible light, so that the beam of a betatron can actually be observed. Of course, this is not much of an advantage, inasmuch as this energy is practically wasted.

The largest betatron in existence at the present time is that belonging to General Electric. It produces a beam of x-rays of 100 mev, and has been in successful operation since August 1943. It weighs 135 tons, and is surrounded by a three-foot concrete wall to protect bystanders from its radiations. The orbit of the electrons is sixty-six inches in diameter, and they traverse their orbit about 250,000 times before being released, all this taking place in 1/240th of a second.

Because of the smaller size of the electrons in comparison with the positively charged particles, they (the electrons) reach high velocities quicker, and consequently the relativistic mass increase begins to be felt at much lower energies. At only one-tenth mev, electrons are already moving at sixty per cent of the velocity of light, and at ten mev their velocity differs from that of light by only a small fraction of a per cent. As a result, at high energies the additional energy supplied goes almost entirely into an increase of mass, and the electrons can be made thousands of times as heavy as they normally are.

The newest particle accelerator is the synchrotron, which developed from the betatron, and also uses electrons as its projectiles. In fact, the synchrotron operates as a betatron until a certain energy level (about 2 mev) is reached, at which time a frequency modulated electric field takes over the task of accelerating the electrons. The only synchrotron in operation at the present time is at the General Electric Laboratory, and produces a beam of seventy mev. Much larger synchrotrons are now in construction at M. I. T., the University of California, and other places.

Strangely enough, the original nuclear machine, the linear accelerator, which was abandoned in favor of the cyclotron, is now receiving considerable attention. New electronic techniques perfected in the development of radar apparently have overcome the difficulties which placed such a low limit on the effectiveness of the linear accelerator. The linear accelerator possesses several obvious advantages over the circular machines. For one thing, it can be enlarged by merely adding new sections; also, since the beam is straight it can be observed at any point along the path, and there is no problem of getting the beam out of the instrument, such as is found in the other accelerators. Consequently, the linear accelerator presents new possibilities.

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THE HEISENBERG UNCERTAINTY PRINCIPLE

(*Continued from page 198*)

$$\Delta\omega = \frac{\Delta E}{\hbar} \sim \frac{1}{\Delta t} \tag{8}$$

This result is familiar in the theory of the modulation of radio waves where the side-bands extend through a region of the order of magnitude of the modulating frequency.

As a more complicated example we can discuss the behavior of the hydrogen atom. We shall obtain an expression for the order of magnitude of the radius of the hydrogen atom in its lowest state. Consider an electron of charge e moving in a circular orbit of radius r around a fixed proton of positive charge e. In order for the electron to be in equilibrium in the orbit, the classical theory demands that the centrifugal force due to the revolution of the electron balance the electrostatic attraction of the proton at the center. That is,

$$\frac{e^2}{r^2} = \frac{mv^2}{r}$$

or

$$\frac{e^2}{r} = \frac{p^2}{m} \tag{6}$$

where $p = mv$ is the momentum of the electron. Using the quantum theory, we know that it is not correct to speak of the electron following a definite orbit. However, by application of the uncertainty relation to the classical model, we can discover the region in which the electron moves most of the time. Since the average value of the momentum of the electron in a given direction is zero, by symmetry, the *rms* deviation is of the same order as the momentum itself. The uncertainty relation then gives

$$p \sim \frac{\hbar}{r} \tag{7}$$

where r is the mean distance of the electron from the proton. Inserting this in equation (6),

$$\frac{e^2}{r} \sim \frac{\hbar^2}{r^2 m}$$

or

$$r \sim \frac{\hbar^2}{me^2} \tag{8}$$

This quantity is just the Bohr radius which is accepted as the radius of the hydrogen atom in its ground state.

As a final example we shall consider an elementary application to nuclear structure. In the early days of nuclear science it was thought that the nuclear β-radiation was due to the escape of electrons trapped in the nucleus. If we consider an electron confined within a nucleus of radius r, the uncertainty relation gives,

$$p \sim \frac{\hbar}{r}$$

as in the previous case. The kinetic energy of the electron is then of the order of magnitude,

$$\frac{1}{2}mv^2 = \frac{p^2}{2m} \sim \frac{\hbar^2}{2mr^2} = \frac{1}{2}\left(\frac{\hbar c}{e^2}\right)^2 mc^2 \left(\frac{r_0}{r}\right)^2$$

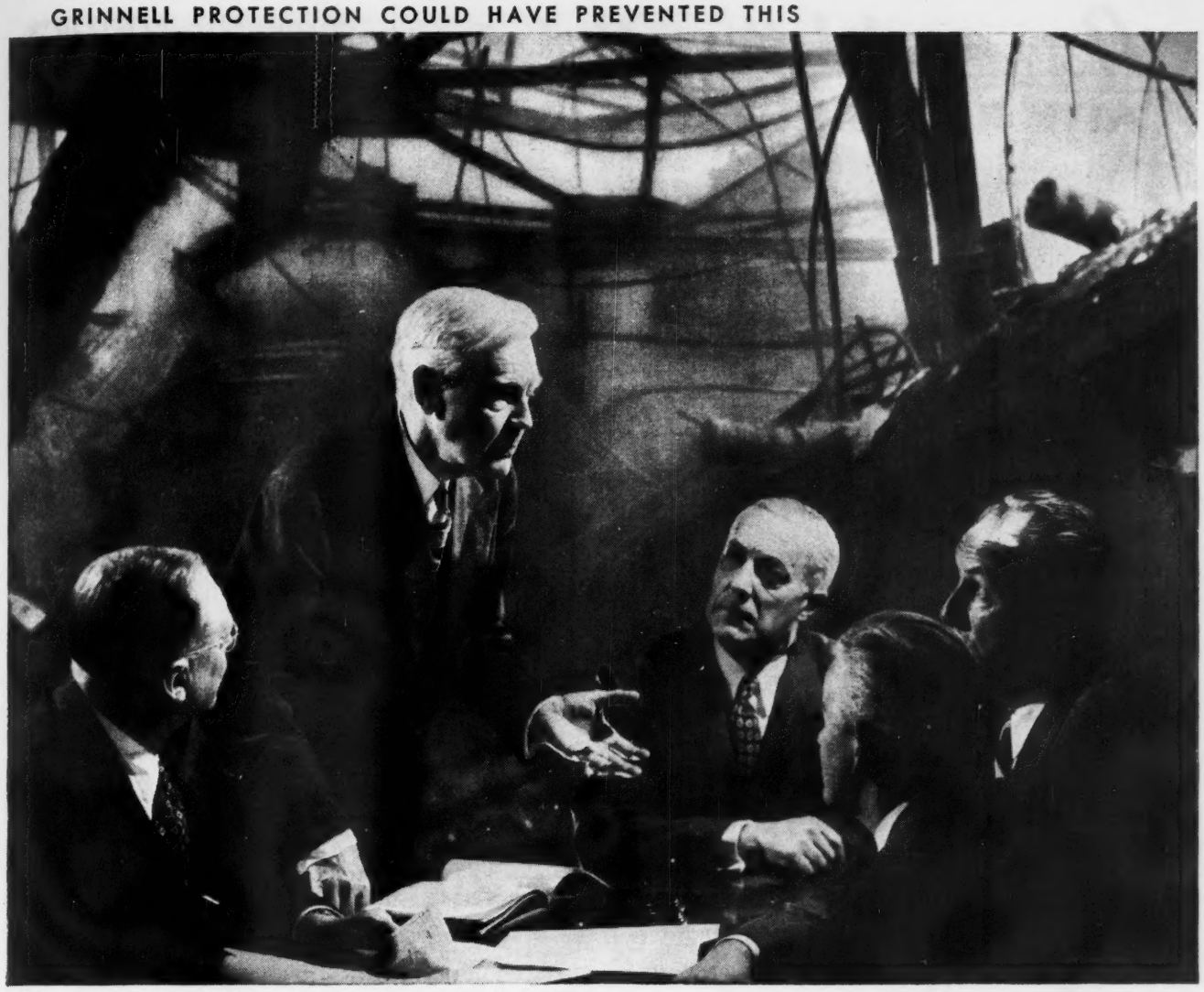
where,

$$\frac{\hbar c}{e^2} = 137 \quad mc^2 = 0.5 \text{ Mev} \quad r_0 = \frac{e^2}{mc^2} \sim 2.8 \times 10^{-13} \text{ cm.}$$

If one substitutes into this expression the values of nuclear radii found by scattering experiments, that is,

(*Continued on page 222*)

GRINNELL PROTECTION COULD HAVE PREVENTED THIS



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YOU: *"I saw to it that we were covered by insurance. Of course it is not adequate for rebuilding at today's prices. We'll need capital — a lot of capital — IF we rebuild."*

THE FACTS: That property cannot be replaced for its insurance value today is but one of five sad aftermaths of fire. The other four, as managers of fire-gutted plants will attest, are: (2) An indemnity check never buys back a lost customer. (3) Burned-out records are lost forever. (4) Employees wander away. (5) Two out of five burned-out businesses never resume operation.

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FROM THE EDITOR'S NOTEBOOK

(*Continued from page 206*)

does as good a job on those as he did on the Atomic Energy Commission, then expect to see something good.

Last, but not least, is **John Weil.** This old-timer, who has been, at one time or another, Make-up Editor, Editor-in-Chief, and General Manager of the TECH ENGINEERING NEWS, is giving us a sort of last look at him with his article in this issue. John is another one of those famous Horace Mann School graduates and heads for New York City between terms. Like Jules Levin, John wants to be a nuclear engineering expert but is interested in the administrative aspects and so is registered in course fifteen; most of his electives are in nuclear science and one of the courses he is taking now is Professor Goodman's.

THE HEISENBERG UNCERTAINTY PRINCIPLE

(*Continued from page 220*)

of the order of several times 10^{-13} cm., one obtains kinetic energies for the electrons of the order of many million electron volts. There was no evidence whatsoever for such high energies in the nucleus and this argument was used as evidence against the existence of electrons in the nucleus. We now know that the nucleus is composed of protons and neutrons.

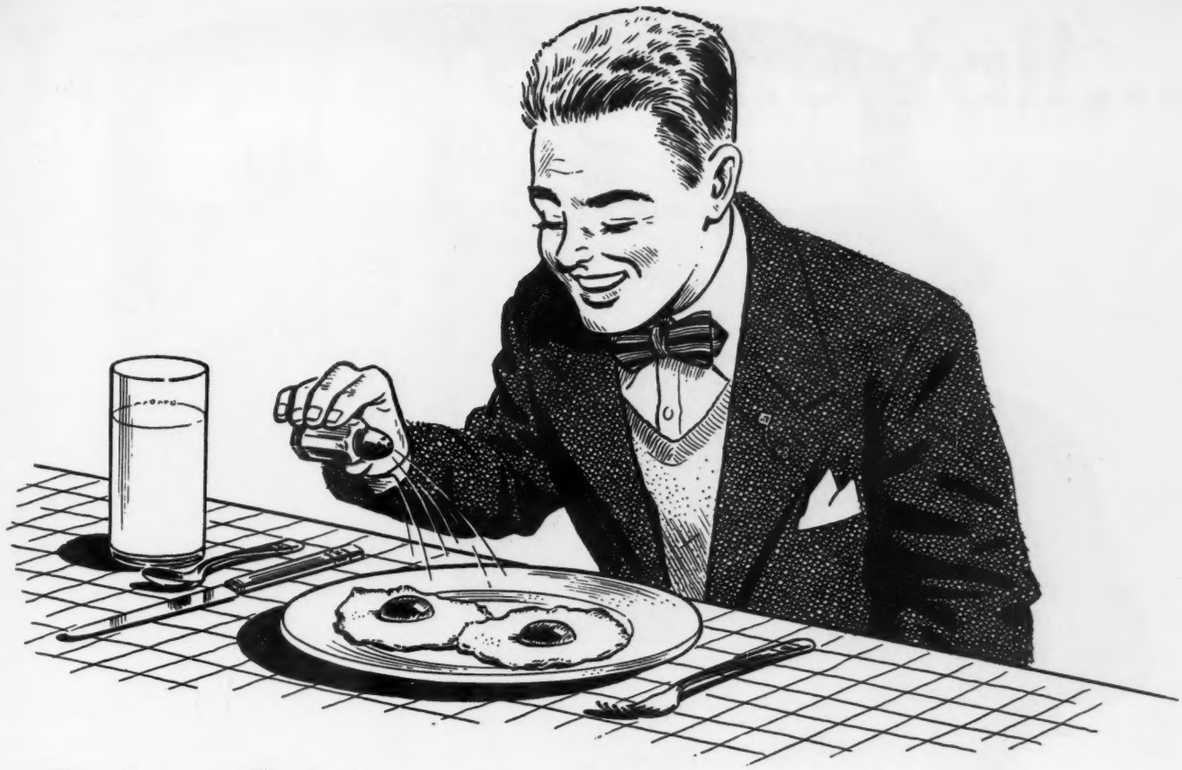
The last two examples we have discussed give a fairly good idea of the applicability of the uncertainty relation in present-day quantum physics. By use of the uncertainty relation the general features of a problem may often be quickly investigated and, often, good values obtained for the order of magnitude of important quantities and processes.

CARS FOR TOMORROW

In the April

T • E • N

Watch for it!



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you put on your eggs...

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The future, too, looks bright for Pennsalt . . . and for the young men who are going to build it. Pennsylvania Salt Manufacturing Company, Philadelphia 7, Pa.

PENN SALT

CHEMICALS

He talked *Chlorine* into an industry

"A great talker"—so a biographer describes James Watt, brilliant father of the steam engine. One can almost visualize him as he regaled his father-in-law, MacGregor, with the time-saving advantages of using "oxygenated muriatic acid" in his bleach works. Chlorine was thus talked into the first commercial bleaching application—an application that changed the entire character of an industry.

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DU PONT Digest
For Students of Science and Engineering

Research simplifies print making with development of "Varigam" Paper

Chemists and physicists make important contributions

Photographic film that has been overexposed or overdeveloped usually means a "hard" or "contrasty" negative—too much silver is deposited on the highlights in comparison with that in the shadows. The opposite effect, a "soft" or "thin" negative, results from underexposure or underdevelopment. At one time photographers had to stock four or five grades of enlarging paper to correct for these conditions and get the right degree of contrast.

To eliminate this expensive, unwieldy situation, scientists developed "Varigam" variable contrast photographic paper. With "Varigam," the whole procedure of getting different degrees of contrast is reversed. Instead of using several grades of paper, the photographer uses only one. He gets variation in contrast by use of filters that control the wave lengths of light reaching the paper, thereby getting finer degrees of contrast than are otherwise possible.

The action of "Varigam" depends on the ability of certain dyes to extend the sensitivity of silver halide emulsions beyond the blue and blue-green regions. This effect was well known to scientists. But "Varigam" has an added feature—it gives high contrast in the blue portion of the spectrum and is also sensitive to light in the green region, *with low contrast.*

"Varigam" the work of many men

The first job was one for the physical chemists. Silver halide emulsions, normally sensitive to blue light, had to be made to give maximum contrast when exposed to light in this region.

It was known that certain dyes would extend the sensitivity of the emulsion over as far as the infra-red. But they were not practical for photographic paper, being affected by the red safety light used in the darkroom. Research by chemists showed that certain dyes such as 1:1′-diethylthiopseudocyanine iodide extended the light sensitivity only to the green region. And, most important, they produced low contrast when used in lower-than-normal concentrations. When such a dye was combined with high-contrast silver halide emulsion, the result was an emulsion that gave high-contrast prints when exposed to blue light, and low-contrast prints when exposed to green light.

Physicists Develop Filters

Physicists made this contrast control a reality by preparing sharp-cutting filters that allow the user to control his printing light selectively. These filters, which are attached to the lens of the enlarger, range from blue for high contrast to yellow, which cuts out the blue almost entirely and gives low contrast. In between are eight grades of filters with intermediate degrees of blue and yellow light transmission. All of the filters are made in such a way that neither light nor printing time needs to be varied as filters are changed, except the last two on the blue end. These require approximately twice the time of the others.

In "Varigam," made by Du Pont, chemical science has given the photographer new economy and convenience in printing, and a degree of contrast control more precise than is possible with any combination of commercial papers.

Questions College Men ask about working with Du Pont

What types of training are needed?

The majority of openings for college graduates at Du Pont are in technical work and are usually in chemical, physical, or biological research; chemical, mechanical, civil, electrical, or industrial engineering. Openings are available from time to time in other fields, including architecture, ceramics, metallurgy, mining, petroleum and textile engineering, geology, mathematics, accounting, law, economics, and journalism. Write for booklet, "The Du Pont Company and the College Graduate," 2521-C Nemours Building, Wilmington 98, Delaware.

DU PONT
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BETTER THINGS FOR BETTER LIVING
...THROUGH CHEMISTRY

More facts about Du Pont — Listen to "Cavalcade of America," Mondays, 8 P.M., EST on NBC

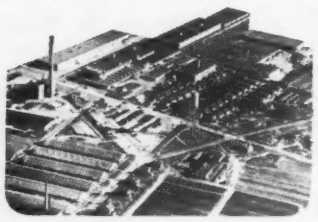
Normal print (center) can be obtained from either a "soft" negative (left) or a "hard" negative (right), using "Varigam" variable contrast paper.

Refrigerated Trucks Loading Frozen Foods.

World's Largest Quick-freezer Uses

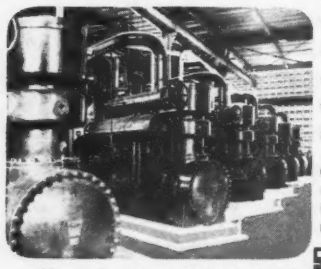
FRICK Refrigeration

Seabrook Farms—Deerfield Packing Corp. are breaking all records for quick-freezing foods at their gigantic plant near Bridgeton, N. J. They are processing as much as a million pounds of vegetables and fruits a day, 85% of which are promptly frozen.



Air View of the Great Plant near Bridgeton, N. J.

Their precooling, quick-freezing and cold storage operations are all handled with Frick Refrigeration. Storage capacity is over 50 million pounds. Twelve big Frick ammonia compressors, driven by motors totaling 3825 horsepower, carry the cooling load with dependability.

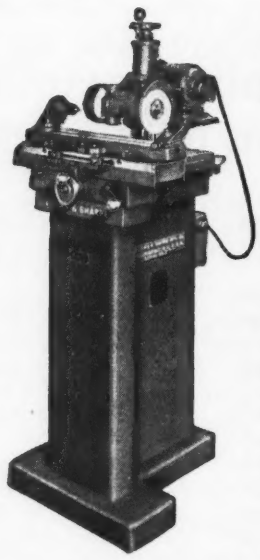


Six of Nine Frick 4-Cyl. Amm. Compressors.

● The Frick Graduate Training Course in Refrigeration and Air Conditioning now in its 31st year is approved under the G.I. Bill of Rights.

DEPENDABLE REFRIGERATION SINCE 1882
FRICK CO.
WAYNESBORO, PENNA. U.S.A.

Look to the Future
when selecting machines



Extra "dividends" can be realized by selecting machines that have a long productive life, simplified operation, accuracy and versatility.

These "dividends" show up in the many new machines recently added to the Brown & Sharpe line, as in the No. 5 Cutter and Tool Grinder shown at the left.

Many unique features developed to meet new conditions, and long trouble-free service life combine to make a profitable investment of Brown and Sharpe

Milling Machines
Grinding Machines
Screw Machines

B·S BROWN & SHARPE MFG. CO.
PROVIDENCE 1, R. I., U. S. A.

BROWN & SHARPE

A BOMB THAT DESTROYS GUESSWORK

ACCELERATED aging tests are part of the Okonite product improvement program. While they cannot replace the study of actual exposure to weather in proving ground and in the field, they have a definite place in estimating the value of electrical insulation.

The oxygen bomb shown at the left is used in accelerated aging tests — one piece of apparatus among many other examples of modern equipment at the service of Okonite engineers and technicians in taking the guesswork out of the manufacture of insulated wires and cables. The Okonite Company, Passaic, New Jersey.

OKONITE OKONITE SINCE 1878 5237
insulated wires and cables

RADIOACTIVE ISOTOPES

(*Continued from page 193*)

than sulfur dioxide is used, the activity will come down with lanthanum fluoride, exhibiting a III state. Therefore neptunium, like uranium, exhibits oxidation states of III, IV, and VI.

Plutonium 238, a decay product of neptunium 238, has been similarly studied. Its reactions are somewhat the same as those of neptunium, but its III state is more stable than the IV. The action of bromic acid is slow, but another oxidizing agent such as persulfuric acid will oxidize the ion to the VI state in which it will precipitate as the uranyl analog.

Research with americium and curium seems to indicate that the III state predominates in both.

The discovery of the transuranic elements has given reason for study of the periodic table position of the elements beyond radium, number 88. Previous to their discovery, the possibility of a second rare earth group was understood, but there was little information as to where such a group might begin.

The chemical properties of actinium, thorium, and protoactinium show that they belong in groups IIIA, IVA, and VA, respectively, just as they are placed in the present periodic table. Although uranium deviates from the expected properties for group VIA, the properties of neptunium and plutonium give important evidence in favor of a new transition group. The properties of neptunium resemble those of uranium, just as the elements of the rare earth group are similar to each other, but are not similar to rhenium which lies directly above it in group VIIIA. Plutonium confirms the evidence given by neptunium, but shows a stronger tendency to the lower oxidation states. Americium and curium show the same tendencies.

Discharge end of continuous tin plating unit showing bright polish of strip after electrolytic plating and high-temperature fusing by Gas-fired radiant burners

CCS

Tin coating is fused to steel as the strip passes between SELAS Gas-fired radiant burners. Close-up of the high-temperature section of the continuous line shown at left

RADIANT GAS BURNERS *create high-temperature* tin-coat fusing zone

BRIGHT FINISHING was the problem—and engineers of Crown Cork and Seal Company, Inc., Baltimore, adopted a high-temperature method for fusing tin to low-carbon strip, with resultant high-polish surface, in a continuous production mill.

Then, to obtain the high temperatures necessary for heat-processing, these engineers selected GAS and modern Gas Equipment. By directing the heat of radiant GAS burners over a concentrated area of the freshly-plated strip it was readily possible to coordinate the fusing action with the plating process to accomplish continuous high-speed production of bright finished strip.

This typical installation demonstrates the flexibility of GAS and the applicability of modern Gas Equipment for continuous, production-line heat processing. Compared with available fuels GAS is most readily controlled by simple automatic devices; Gas Equipment can be adapted for use with existing machinery or incorporated in new machinery without radical design changes, or expensive supplemental apparatus.

Manufacturers of Gas Equipment and the American Gas Association support continuing programs of research designed to assure the most efficient use of GAS for every heat-processing requirement.

AMERICAN GAS ASSOCIATION
420 LEXINGTON AVENUE, NEW YORK 17, N. Y.

MORE AND MORE...
THE TREND IS TO GAS
FOR ALL INDUSTRIAL HEATING

Careers at GENERAL ELECTRIC

PHYSICIST . . . CHEMIST . . . ENGINEER

for each, General Electric has assignments to his liking

General Electric is not one business, but an organization of many businesses, ranging from the building of giant turbines at Schenectady to the molding of plastics in Pittsfield. The 165,000 people of General Electric work in 93 plants in 16 states. Graduates of American colleges and universities are finding that General Electric offers opportunities to all degrees of specialists, all sorts of enthusiasms, all kinds of careers.

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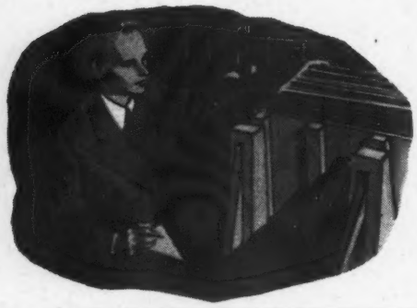
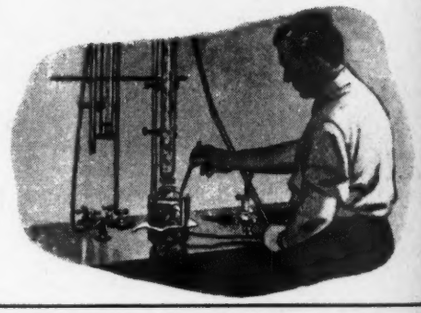
ATOMIC PHYSICIST



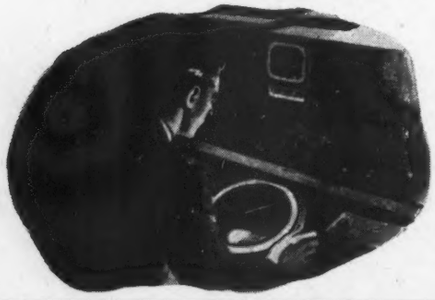
As the result of its research in nucleonics, General Electric was asked by the Government in 1946 to take over operation of the giant Hanford Works, one of the major units of the Manhattan Project. With this development, and with the construction of both a new Atomic Power Laboratory and a new Research Laboratory at Schenectady, opportunities in all phases of nuclear research have increased enormously. Herbert C. Pollock (left), one of the first scientists to isolate U-235, works now with such electron accelerators as the Betatron and Synchrotron.

CHEMIST

General Electric is the largest molder of finished plastics parts in the world. It has also played a large part in the development of silicones, new chemical compounds from which a whole new industry is springing. Developments like these have meant unprecedented opportunities for chemists and chemical engineers at General Electric. Dr. J. J. Pyle, graduate in chemistry at British Columbia and McGill, became director of the G-E Plastics Laboratories at the age of 29.



ELECTRONICS SPECIALIST



For good reason, General Electric Electronics Park has been called the "Greatest Electronics Center in theWorld." Its 155 acres look like a campus. Its laboratories, shops and production lines are the most modern of their kind. It's a Mecca for men whose attentions perk up at the sight of a circuit diagram—men like Dick Longfellow, who has worked his way up through television and high-frequency assignments and is today section engineer in charge of ground radar equipment.

FOR YOUR COPY OF "CAREERS IN THE ELECTRICAL INDUSTRY," WRITE TO DEPT. 237-6, GENERAL ELECTRIC CO., SCHENECTADY, N. Y.

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